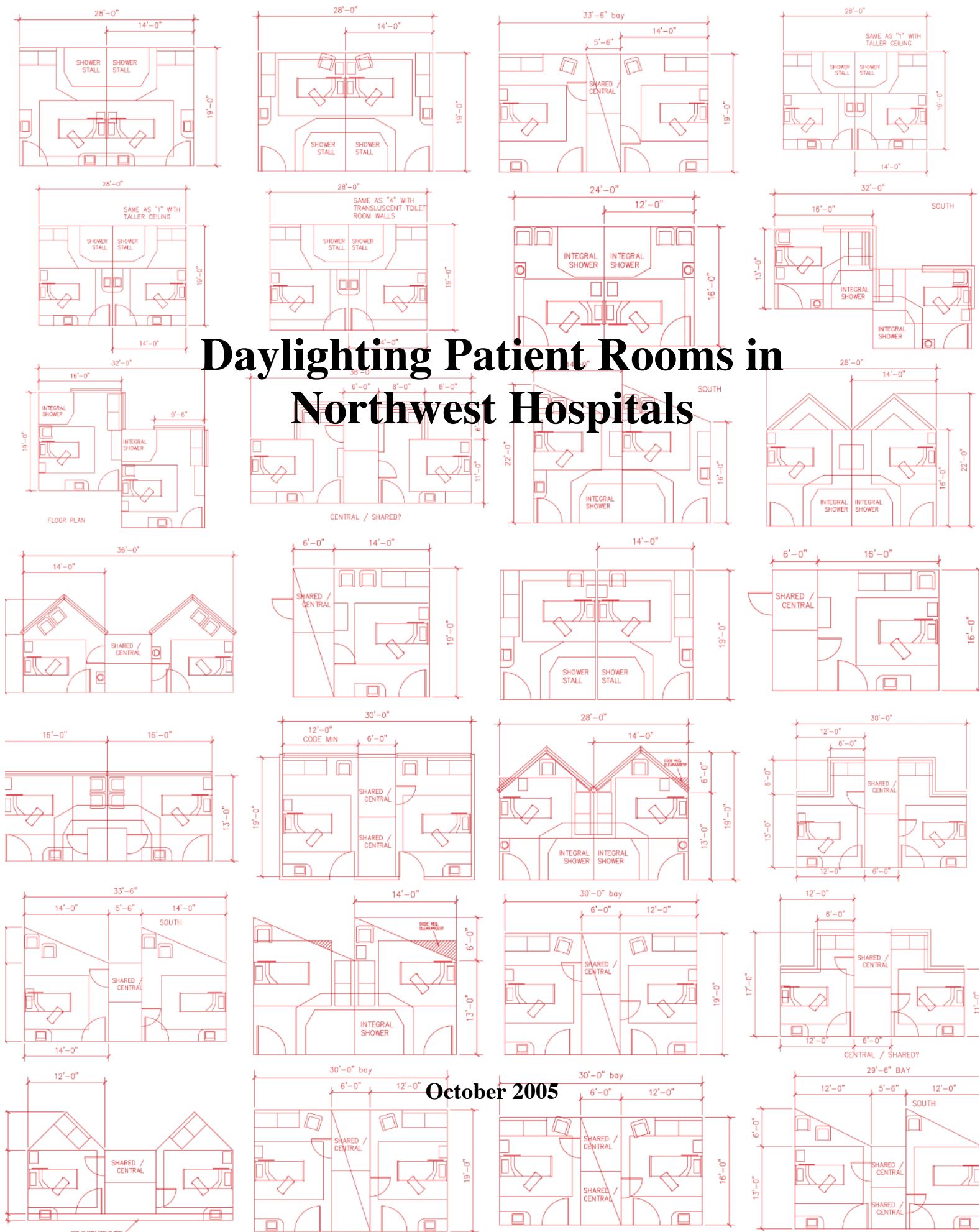


Daylighting Patient Rooms in Northwest Hospitals



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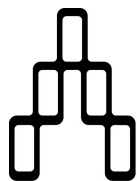
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CONTENTS

SUMMARY	1
RELATIONSHIPS AMONG ROOM DESIGN, DAYLIGHTING AND PATIENT WELL-BEING.....	1
EXAMPLE DAYLIT HOSPITAL ROOM DESIGNS.....	6
EFFECTS ON OTHER SYSTEMS	16
1.0 INTRODUCTION	38
1.1 THE IMPORTANCE OF DAYLIGHT	38
1.2 CASES AND EXAMPLES FROM CURRENT PRACTICE	38
<i>Universal Room Design</i>	38
<i>Access To Daylight</i>	39
<i>Structure & HVAC</i>	39
2.0 FACTORS THAT AFFECT DAYLIGHTING AND PATIENT WELL-BEING.....	40
2.1 POTENTIAL EFFECTS OF DAYLIGHT AND VIEW WINDOWS ON ENERGY CONSERVATION	41
2.2 PSYCHOLOGICAL WELL-BEING	42
<i>Benefits of Daylight</i>	42
<i>Benefits of Good Views</i>	43
2.3 DAYLIGHT	44
<i>Light Levels and Distribution</i>	44
<i>Glare</i>	45
<i>View Potential</i>	45
2.4 ELECTRIC LIGHT	49
<i>Electric Lighting Configuration</i>	49
<i>Controls</i>	49
2.5 WINDOWS	50
2.6 INTERIOR CONFIGURATION.....	50
<i>Zoning</i>	50
<i>Reflectivity</i>	52
2.7 ROOM GEOMETRY	53
<i>Room Dimensions</i>	53
<i>Edge Condition</i>	53
<i>Ceiling Height and Configuration</i>	54
<i>Toilet Location</i>	54
2.8 STRUCTURE AND HVAC	55
<i>Structure</i>	55
<i>HVAC & Mechanical Systems</i>	57
3.0 ANALYSIS AND PHYSICAL MODEL TESTING.....	58
3.1 ANALYTICAL SKY COMPONENT CALCULATIONS	61
3.2 TEST MATRIX.....	64
3.3 TEST ASSUMPTIONS AND GENERAL PROCEDURES	65
3.4 OVERVIEW OF TEST MODELS	66
<i>Structure and Room Height</i>	66
<i>Toilet Rooms</i>	66
<i>Edge Condition</i>	67
<i>Window Size & Sill Height</i>	67
4.0 TEST RESULTS	68

4.1 MODEL RANKINGS	68
<i>Perceived Quality of Daylight</i>	68
<i>Light Intensity</i>	69
<i>View Potential</i>	69
<i>Electric Savings</i>	69
4.2 OBSERVATIONS	70
<i>Toilet Size and Location</i>	70
<i>Sill Height</i>	71
<i>Edge Conditions</i>	73
<i>Ceiling Configuration</i>	75
<i>Room Dimensions</i>	77
4.3 TESTING RESULTS SUMMARY	80
4.4 ELECTRIC SAVINGS	81
5.0 BARRIERS TO CHANGE	82
6.0 TOOL FOR DESIGNING DAYLIT PATIENT ROOMS	84
APPENDIX A – BIBLIOGRAPHY WITH ANNOTATIONS	86
APPENDIX B – DETAILED TEST MATRIX	92
APPENDIX C – TEST MODEL CONFIGURATIONS & DAYLIGHT FACTOR CONTOURS.....	93

SUMMARY

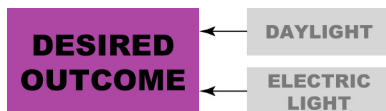
This section is intended to enable hospital design professionals to quickly understand the basic principles of hospital patient room daylighting design in order to apply them in their current design projects. It delineates the important variables such as room width and depth, and describes how they interact. The section concludes with 10 prototype patient room designs that represent a range of possibilities for typical hospital design.

The potential benefits from daylighting patient rooms are energy savings and increased patient well-being. Lights can be turned off when daylight is available, saving electrical energy. Turning off the electric lights can reduce internal heat gain, which in turn reduces the size of the cooling system, reducing both initial and operating costs. Proper placement of the windows increases the opportunity for views and the availability of daylight, both of which can improve patient well-being.

RELATIONSHIPS AMONG ROOM DESIGN, DAYLIGHTING AND PATIENT WELL-BEING



Daylighting of hospital rooms is complex and affects both the architecture and the supporting HVAC and structural systems, and can potentially affect current caregiver routines and attitudes. The desired outcome of patient room daylighting is increased energy savings and patient well-being (1) (numbers in parentheses refer to Figure 1). This outcome is dependent on a number of factors: daylight, electric light, windows, interior configuration, room geometry, structure, HVAC, and their context. These factors and their relationships are illustrated in Figure 1 and are discussed in greater detail in Section 2.



The desired outcomes of daylighting patient rooms are reduced lighting energy use (1A) during daylight hours due to turning off electric lighting (savings can be up to 87%), and increased patient well-being as a result of providing daylight and a view (1B), thereby potentially shortening the time the patient occupies a room. Both of these outcomes depend on the character of the daylight (2) and electric lighting (3) that is provided.

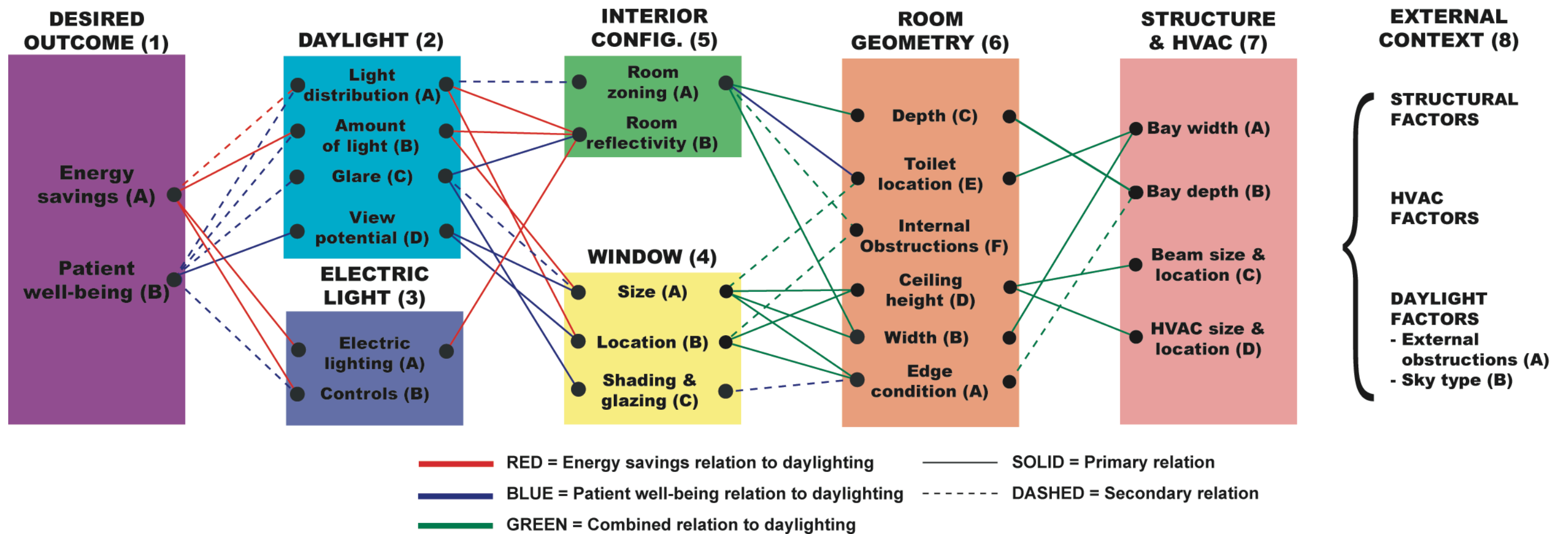


Figure 1 - Patient room daylighting elements

This figure illustrates the relationship of elements that make up hospital daylighting design. The desired outcomes, as represented by the block at the far left, are energy savings and patient well-being. These outcomes are dependent on daylighting and electric lighting, which are in turn dependent on the windows and interior configuration, room geometry, structure and HVAC, and external context. The red lines indicate relationships pertaining to energy savings, the blue lines indicate relationships pertaining to patient well-being, and the green lines indicate relationships that pertain to both energy savings and patient well-being. Solid lines indicate a primary relationship; dotted lines indicate a secondary relationship.



Daylighting is provided by *daylight glazing* – that is, glazing with the primary purpose of introducing daylight into a space to reduce the use of electric light. In addition to daylight glazing, there is *view glazing*, which has the primary purpose of providing external views. Both glazing types admit light that is of potential benefit to patient well-being.

Daylighting must supply the illumination both where it is needed (2A) and at the desired level (2B). Typically, patient rooms are divided into three zones: one for the patient, one for the caregiver, and one for the family and visitors. The amount of task lighting needed for a medical examination is 50 footcandles, the task lighting amount required to read in bed is 30 footcandles, while the amount of ambient lighting needed for navigation and spatial definition is 10 footcandles.

The different zones and distribution of daylight should be designed to minimize glare or visual discomfort (2C) for the patient, family, and caregiver. Glare occurs with the presence of bright light sources in the field of view compared to the illumination levels to which the patient, caregiver or family members are adapted. View openings (2D) should be designed to provide the patient with desired vistas that include ground plane, distant objects, and the sky. Glare can be reduced by eliminating the daylight window from the field of view with light shelves or blinds that allow the daylight window to maintain its contribution to the interior light levels while avoiding glare or visual discomfort for the viewer.



Electric lighting (3A) should be designed and controlled (3B) to take advantage of available daylighting by dimming or shutting off completely. Task ambient electric lighting design strategies work well with daylighting because room ambient light levels are lower than task lighting requirements, making them easy to supply with daylight. Ambient daylight is supplemented with task electric lighting just in the areas where it is needed as opposed to lighting the whole room to task levels. Automatic dimmable indirect lighting luminaries make the transition from electric lighting to daylighting and back unnoticeable as sky conditions change.



All of the daylighting factors are dependent on the windows (4) in the room. Given a fixed room size or daylight zone, the size (4A) of the windows will have the largest effect on the distribution of daylight in that fixed space. The window's location (4B) also plays a major role in the

daylight distribution. A 2-foot-high window with a 12-foot head height will allow daylight to penetrate further into the room than the same sized window with a 10-foot head height because the higher window “sees” a brighter portion of the sky. Additional important factors are the shading and glazing (4C) of the windows. As the windows allow light in and out of the room, they also allow thermal energy in and out of the room through solar gain and conduction gain and loss. The proper choice of glazing as well as external shades and internal light shelves and shades can maximize the daylighting potential while minimizing heat gain and loss. Different glazing types have different performance characteristics such as the visible transmission (V_T), heat transfer properties (U value) and the solar heat gain coefficient (SHGC). These factors can have a large effect on the amount of light and thermal energy passing through the window. Figure 2 shows values for these properties for typical view and daylight glazing.

	View Glazing	Daylight Glazing
V_T	50%	70%
U value	0.25	0.29
SHGC	0.39	0.38

Figure 2 - Properties of typical view and daylight glazing

Different types of glazing should be used on the daylighting and view windows in order to optimize daylighting while reducing glare. For example, the view window can use glazing with a V_T of 50% in order to reduce brightness, while the daylight window can have a V_T of 70% in order to maximize the daylight through the window. Shading devices such as shade cloth rollers, blinds, louvers and awnings can also be used to minimize glare. Shading devices effectively reduce the window aperture size, thus reducing the amount of light admitted. Because external illumination levels can vary from 500 to 10,000 or more footcandles, it is essential to have a shading strategy that allows for adjusting aperture size or fixing the aperture at a midrange size to reduce heat gain. For example, a person facing an unshaded north-facing view and daylight windows in June at a distance of six feet may experience a glare index of 275, a value well into the range of visual discomfort. Given the same situation, but with an external fixed overhang, an internal light shelf and an internal shade with a 25% light transmission factor, the glare index reduces to 60, which is an acceptable value.



How the room is zoned (5A) determines the amount of daylight available to the patient, family and caregivers. Since hospital rooms typically use side lighting (i.e. no overhead skylights), the zone nearest the window receives the most light. Ideally, zones with tasks that require higher levels of illumination should be located closer to the windows. Older adults need 250-300 footcandles in order to maintain circadian rhythms (Noell-Waggoner, p. 7).

High values for the reflectivity of the surfaces in the room (5B) – 70% to 90% or more – will result in a higher overall level of daylight in the space. The reflectivity of the surfaces in a room is also key to obtaining an even distribution of light and the reduction of glare.



Closely linked to the interior configuration of the room is the room’s geometry (6). The configuration of the window wall, or the edge condition (6A), influences the amount of light at the perimeter and, perhaps more importantly, provides the opportunity for varied patient views. A major factor in the room’s geometry is the room width (6B), which partly dictates the window width (size) as well as the flexibility of occupancy zoning. A sufficiently wide room may allow two occupancy zones direct access to the windows on the outer wall. In analytic testing, 16’ wide rooms performed better than 14’ and 12’ rooms. Other room geometry factors have similar effects, such as room depth (6C) – which affects the light levels at the back of the room – and ceiling height (6D) – which affects the window head height. Room depth is a primary determinate of the daylight factor at the back of the room. Thirteen-foot deep rooms performed better than the 16’ deep rooms, which performed better than the 19’ deep rooms. Rooms with 10’ ceilings performed better than those with lower ceiling heights.

The toilet room is an internal obstruction, and its size and placement (6E) have a significant effect on the distribution of daylight. For example, locating the toilet room on the window wall has a negative effect on the daylighting, reducing the window size and the overall amount of daylight entering the room. Overall, the best toilet placement was found to be the shared-wall configuration, which performed better than the inboard and outboard configurations. Configurations with smaller toilet rooms (42 s.f. integrated shower) performed better than those with larger toilet room types (54 s.f. tub room and 68 s.f. shower stall room). As with the toilet rooms, other internal obstructions (6F) affect daylighting. Items such as medical equipment, large pieces of furniture, etc. should be located around the perimeter of the room and away from the window wall so as to minimize interference with light flow into the room.



The width and depth of the room are largely determined by the structural and HVAC systems for the building (7). The room geometry and the attendant factors discussed to this point can be thought of as a “daylit container,” which is in turn wrapped in a structural and HVAC “envelope.” This is not to imply, however, that the designs for the “container” and the “envelope” are independent – the opposite is true. The room dimensions are constrained by the bay size for the given structural system selected (7A/B), with a typical bay sizes ranging from 28’0” to 32’6”. The potential head height of the window is determined by the need for, size of, and placement of the perimeter beam (7C). Window head heights can be as high as 10’ for normal configurations, or 12’ with an upturned perimeter beam and sloped ceiling. The size and location of the HVAC ducts (7D), combined with the structural system’s beam sizes, determine

the depth of the ceiling cavity and the ceiling height. Typically, a 12"x12" supply duct and a 28"x10" return duct must be fit into the ceiling plenum. An additional 12"x12" exhaust duct may also be used. Depending on the way the "container" and the "envelope" are configured, substantial savings in construction costs through reduced floor-to-floor height may be realized alongside reduced energy costs.

STRUCTURE
& HVAC

EXTERNAL
CONTEXT

External obstructions can reduce the amount of light received by the window by obstructing the sky, especially objects with low reflectance like trees. The amount of light to the window can also be increased by reflection off a bright surface like a snow-covered ground plane.

Most northwest climates in highly populated areas are predominantly overcast, although they do exhibit extended clear sky periods. A fully overcast sky varies in brightness by a factor of 3 from the horizon to the zenith but doesn't vary with orientation. A clear sky is the reverse: it is brightest at the horizon and darkest at the zenith, with the exception of the sun and the area around it, which is approximately ten times brighter than the overcast sky. Daylight windows should be designed to "see" the brightest part of the overcast sky but should be configured to block direct sun from the room and reduce heat gain during clear sky periods.

EXAMPLE DAYLIT HOSPITAL ROOM DESIGNS

This section contains ten prototypes that represent a variety of layouts that typically had good daylighting performance characteristics when compared to a baseline outboard toilet model. There are many architectural variations that are possible within these examples that provide equal daylighting and patient well-being. Some of these are shown as sketches of alternate room layouts, view window options, and shading choices.

- 1) **Outboard Typical** (Model 1) – This room design represents the characteristics of many hospital rooms currently being designed. This baseline room has standard dimensions of 14' wide by 19' long, and features an outboard shower stall toilet. This configuration results in poor daylighting performance, because the outboard toilet does not allow much exterior glazing. This model has a 14' floor-to-floor height.
- 2) **Inboard Typical** (Model 2) – This room design is nearly identical to the "Outboard Typical" model, with the exception that the shower stall toilet has been moved to the inboard position. The daylighting represents a marked improvement over the "Outboard Typical" and demonstrates the effect of toilet location on daylighting performance. This model has a 14' floor-to-floor height.
- 3) **Light-Through Typical** (Model 5) – This room design is an attempt to make a compromise between good daylighting and the need to have the toilet located on the outboard wall. The layout is essentially the same as the Outboard Typical model, but with translucent toilet room walls. This allows for light from the glazing in the toilet room to penetrate into the back of the room, improving the overall daylighting performance. The

glazing would be made of fluted glass to preserve patient privacy. This model has a 15' floor-to-floor height.

- 4) **Square** (Model 16) – This room design has an equal width and depth of 16', a slanted ceiling allowing for higher window head height and better daylighting performance, and shared-wall toilets. This model has a 15' floor-to-floor height.
- 5) **Wide** (Model 17) – This room design is wider than it is deep (16'w x 13'd), allowing for higher daylight values at the back of the room. This effect is enhanced by the high window head heights allowed by the slanted ceiling. This model has a 15' floor-to-floor height.
- 6) **Narrow, High Ceiling** (Model 23) – This room design is long and narrow (12'w x 19'd), but has good daylight penetration due to the shared-wall toilets and large daylight glazing afforded by the low sill. This model has a 14' floor-to-floor height.
- 7) **Narrow, Low Ceiling** (Model 26) - This room design is essentially the same as the “Narrow, High Ceiling” configuration, except that it has a more compact 12' floor-to-floor height. The slanted ceiling allows for a higher window head height, which still permits good daylight in the room.
- 8) **Chevron** (Model 12) - This room design has a pointed outer wall, which allows for more daylighting and view glazing for an average room width. Similar in features to the “Inboard Typical” model, this room features an inboard toilet that does not obstruct daylight. This model has a 14' floor-to-floor height.
- 9) **Corner** (Model 24) – This room design has shared-wall toilets and a notched outer wall, allowing for good daylight distribution throughout the space. This model has a 13' floor-to-floor height.
- 10) **Diagonal Champ** (Model 28) – This was the top-ranking design for daylight distribution. The room features a slanted outer wall and slanted ceiling, with shared-wall toilets. This model has a 13' floor-to-floor height.

Model 1 - Outboard Typical



Figure 3 - "Outboard Typical" configuration (Model 1). View window options are: A) Recommended view apertures from Glare calculations, B) Maximum view window, C) Maximum view window with operable shutters or louvers (do diminish backlighting of family members sitting on bench in front of window), D) Recommended view apertures with addition of a mirror placed on wall to increase perceived size of view window.

Performance Evaluation – “Outboard Typical” (Model 1)

This room design represents the characteristics of many hospital rooms currently being designed. This baseline room has standard dimensions of 14’ wide by 19’ long, and features an outboard shower stall toilet. This configuration results in poor daylighting performance, because the outboard toilet does not allow much exterior glazing. This model has a 14’ floor-to-floor height.

Annual Savings

The annual electricity savings for this room is 73 kWh. The electric savings is due to reduced electric light use during daylight hours only. This savings estimate assumes a 0.7 W/sq.ft. power density, a target d.f. of 30 footcandles, and a continuous dimming lighting system. With an electric rate of \$0.045/kWh, the annual savings for this room would be \$3.30.

Well-Being

This design represents a baseline case representative of many patient rooms with outboard toilets. It is poorly daylit and the small free wall area limits view potential. Consequently, it will most likely not have a positive effect on patient well-being.

Fenestration

- Size – The daylight window is 1’ high by 5’6” wide.
- Placement – Eight feet of the 14’ outer wall is taken up by the toilet room. The daylight window runs along the length of the remaining 6’ of outer wall, with a sill height of 8’ and a head height of 9’.
- Glazing – Glazing for the daylight window has $V_T=70\%$, $U=0.28$, $SHGC=0.38$. Alternate glazing for the daylight window may be used to reduce visible transmission and heat gain (see Shading below).
- Glare – The glare constant for the daylight window is 61. This is measured from an observation point centered on the daylight window, 10’ from the outer wall and 48” from the floor, with the line of sight perpendicular to the outer wall.
- View potential – The view window can be located within an area 7’9” high by 6’ wide, for a total view potential of 46.5 s.f.

Visual Comfort

- The view window is 2’6” high by 4’ wide and is centered on the daylight window, with a sill height of 3’ and a head height of 5’6”. Glazing for the view window has $V_T=50\%$, $U=0.25$, $SHGC=0.39$. The view window was sized based on the assumptions that the daylight window was not in the field of view (hidden by a light shelf or fixed horizontal blinds) and that the adaption level of the viewer was equal to 10 footcandles.
- The maximum glare constant for the combined daylight window and view window should be 150.
- When the patient’s visitors are located in front of the view glazing they will be backlit, making it difficult for the patient to see the facial expressions of the visitors.

Shading

The visible transmission through the daylight window must be reduced to 10% in order to achieve the desired illumination goal. A roll-up shade can be used to achieve this goal. Alternately, the use of translucent insulation, such as Kalwall, as the primary glazing for the daylight window can reduce the solar gain and maintain illumination values at a suitable level.

Lighting & Controls

- The electric lights are assumed to be occupancy- and photo-controlled, with manual override.
- The shades on the daylight windows should be motorized or automated. Control of the aperture size is critical to having enough light on overcast days but not too much on sunny days. View glazing shades can be automatic or manual.

Effects on Other Systems

- HVAC – No effect on the HVAC system.
- Structural – No effect on the structural system.
- Cost – No effect on cost.

Model 2 - Inboard Typical

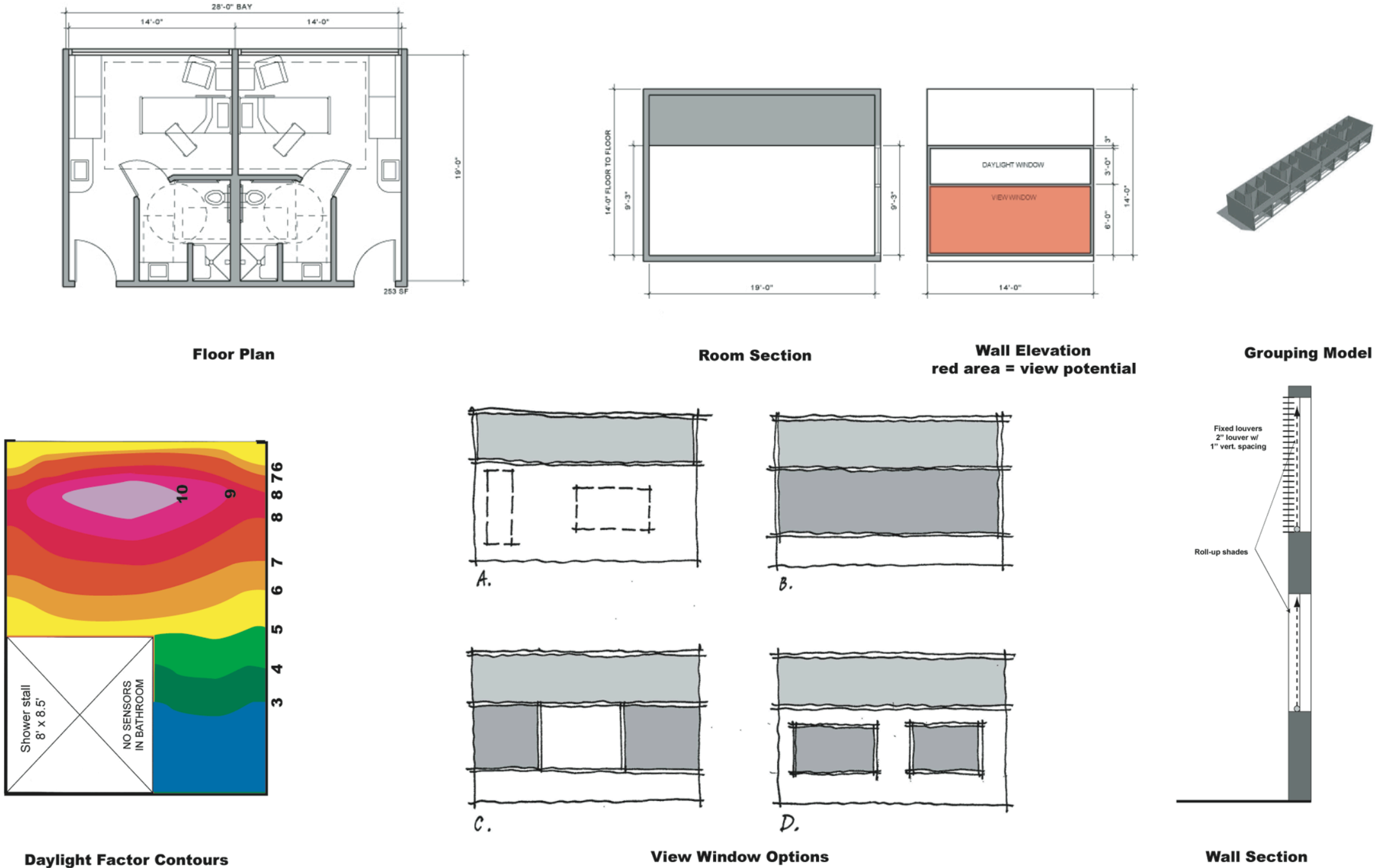


Figure 4 - "Inboard Typical" configuration (Model 2). View window options are: A) Recommended view apertures from Glare calculations, B) Maximum view window, C) Separated patient view and family view windows paired with adjacent room windows, D) Separated patient view and family view windows as punched openings.

Performance Evaluation – “Inboard Typical” (Model 2)

This room design is nearly identical to the “Outboard Typical” model, with the exception that the shower stall toilet has been moved to the inboard position. The daylighting represents a marked improvement over the “Outboard Typical” and demonstrates the effect of toilet location on daylighting performance. This model has a 14’ floor-to-floor height.

Annual Savings

The annual electricity savings for this room is 693 kWh. The electric savings is due to reduced electric light use during daylight hours only. This savings estimate assumes a 0.7 W/sq.ft. power density, a target d.f. of 30 footcandles, and a continuous dimming lighting system. With an electric rate of \$0.045/kWh, the annual savings for this room would be \$31.20.

Well-Being

This design will have a positive effect on patient well-being as it allows for a well-lit room and has a large view potential. The patient will benefit from a close proximity to the windows.

Fenestration

- Size – The daylight window is 3’ high by 13’6” wide.
- Placement – The daylight window runs along the length of the outer wall, with a sill height of 6’ and a head height of 9’.
- Glazing – Glazing for the daylight window has $V_T=70\%$, $U=0.28$, $SHGC=0.38$. Alternate glazing for the daylight window may be used to reduce visible transmission and heat gain (see Shading below).
- Glare – The glare constant for the daylight window is 102. This is measured from an observation point centered on the daylight window, 10’ from the outer wall and 48” from the floor, with the line of sight perpendicular to the outer wall.
- View potential – The view window can be located within an area 5’9” high by 14’ wide, for a total view potential of 80.5 s.f.

Visual Comfort

- The view window is 2’6” high by 4’ wide and is centered on outer wall, with a sill height of 3’ and a head height of 5’6”. Glazing for the view window has $V_T=50\%$, $U=0.25$, $SHGC=0.39$. The view window was sized based on the assumptions that the daylight window was not in the field of view (hidden by fixed horizontal blinds) and that the adaption level of the viewer was equal to 10 footcandles.
- The maximum glare constant for the combined daylight window and view window should be 150.
- When the patient’s visitors are located in front of the view glazing they will be backlit, making it difficult for the patient to see the facial expressions of the visitors.

Shading

The visible transmission through the daylight window must be reduced to 10% in order to achieve the desired illumination goal. A roll-up shade can be used to achieve this goal.

Alternately, the use of translucent insulation, such as Kalwall, as the primary glazing for the daylight window can reduce the solar gain and maintain illumination values at a suitable level.

Lighting & Controls

- The electric lights are assumed to be occupancy- and photo-controlled, with manual override.
- The shades on the daylight windows should be motorized or automated. Control of the aperture size is critical to having enough light on overcast days but not too much on sunny days. View glazing shades can be automatic or manual.

Effects on Other Systems

- HVAC – The HVAC ducts may need to be altered to accommodate the decreased floor-to-floor height.
- Structural – No effect on the structural system.
- Cost – There will be a minor increase in cost due to the increased glazing, but this should be offset by the reduced floor-to-floor height.

Model 5 - Light-Through Typical

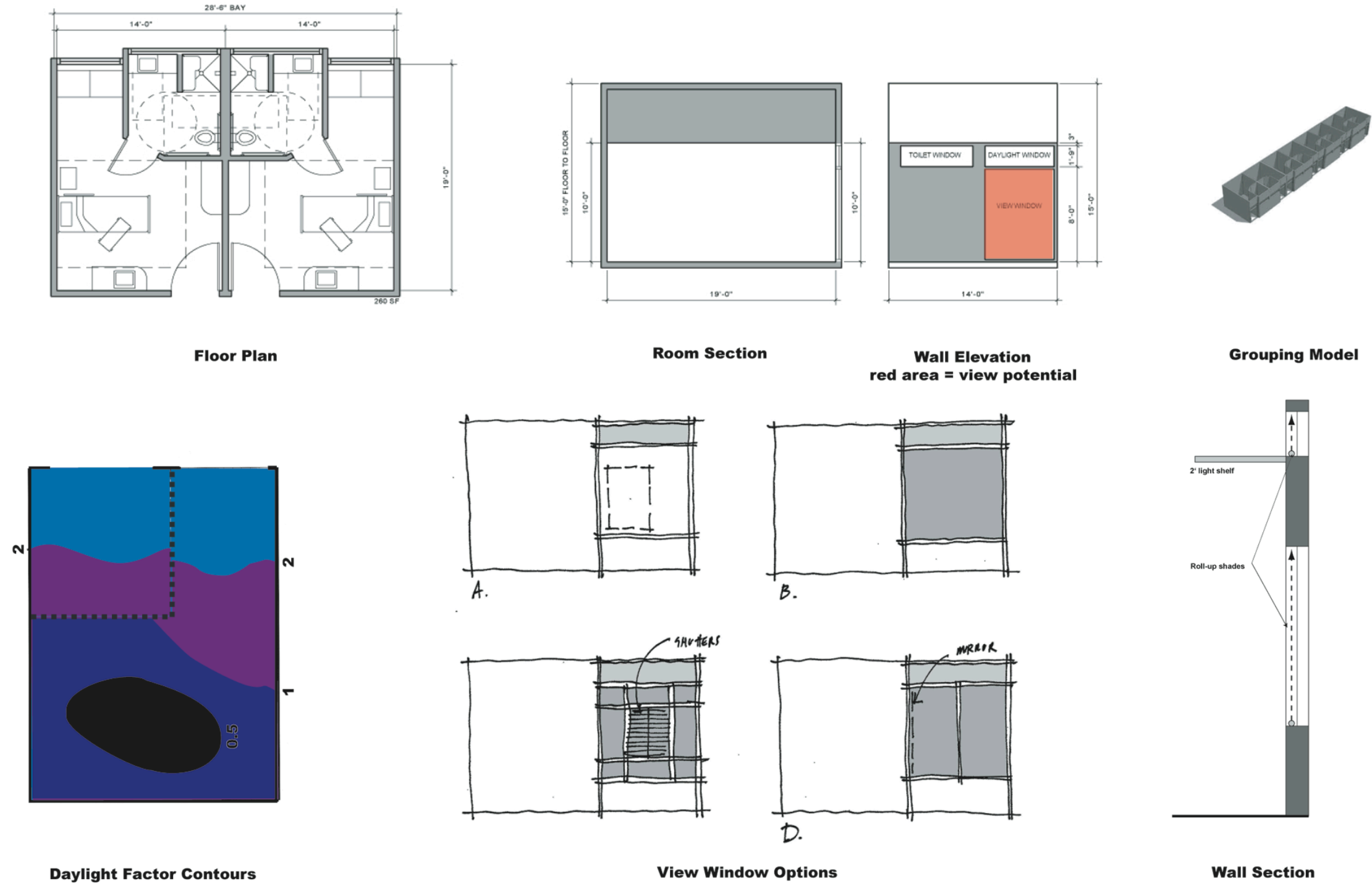


Figure 5 - “Light-Through Typical” configuration (Model 5). View window options are: A) Recommended view apertures from Glare calculations, B) Maximum view window, C) Maximum view window with operable shutters or louvers (do diminish backlighting of family members sitting on bench in front of window), D) Recommended view apertures with addition of a mirror placed on wall to increase perceived size of view window.

Performance Evaluation – “Light-Through Typical” (Model 5)

This room design is an attempt to make a compromise between good daylighting and the need to have the toilet located on the outboard wall. The layout is essentially the same as the Outboard Typical model, but with translucent toilet room walls. This allows for light from the glazing in the toilet room to penetrate into the back of the room, improving the overall daylighting performance. The glazing would be made of fluted glass to preserve patient privacy. This model has a 15' floor-to-floor height.

Annual Savings

The annual electricity savings for this room is 310 kWh. The electric savings is due to reduced electric light use during daylight hours only. This savings estimate assumes a 0.7 W/sq.ft. power density, a target d.f. of 30 footcandles, and a continuous dimming lighting system. With an electric rate of \$0.045/kWh, the annual savings for this room would be \$13.95.

Well-Being

This design represents a variation on the baseline case, with translucent toilet walls that allow for greater daylight penetration. However, it is still relatively dark and the small free wall area limits view potential. Consequently, it will most likely not have a noticeably positive effect on patient well-being.

Fenestration

- Size – The primary daylight window is 1'9" high by 5'6" wide. The toilet room window is 2' high by 6' wide.
- Placement – Eight feet of the 14' outer wall is taken up by the toilet room. The primary daylight window runs along the length of the remaining 6' of outer wall, with a sill height of 8' and a head height of 9'9". The toilet room window is centered on the outer wall of the toilet room, with a sill height of 7'9" and a head height of 9'9".
- Glazing – Glazing for the daylight window has $V_T=70\%$, $U=0.28$, $SHGC=0.38$. Alternate glazing for the daylight window may be used to reduce visible transmission and heat gain (see Shading below).
- Glare – The glare constant for the daylight window is 69. This is measured from an observation point centered on the daylight window, 10' from the outer wall and 48" from the floor, with the line of sight perpendicular to the outer wall.
- View potential – The view window can be located within an area 7'9" high by 6' wide, for a total view potential of 46.5 s.f.

Visual Comfort

- The view window is 4' high by 2'6" wide and is centered on the daylight window, with a sill height of 2' and a head height of 6'. Glazing for the view window has $V_T=50\%$, $U=0.25$, $SHGC=0.39$. The view window was sized based on the assumptions that the daylight window was not in the field of view (hidden by fixed horizontal blinds or a light shelf) and that the adaption level of the viewer was equal to 10 footcandles.
- The maximum glare constant for the combined daylight window and view window should be 150.

- When the patient's visitors are located in front of the view glazing they will be backlit, making it difficult for the patient to see the facial expressions of the visitors.

Shading

The visible transmission through the daylight window must be reduced to 10% in order to achieve the desired illumination goal. A roll-up shade can be used to achieve this goal.

Alternately, the use of translucent insulation, such as Kalwall, as the primary glazing for the daylight window can reduce the solar gain and maintain illumination values at a suitable level.

Lighting & Controls

- The electric lights are assumed to be occupancy- and photo-controlled, with manual override.
- The shades on the daylight windows should be motorized or automated. Control of the aperture size is critical to having enough light on overcast days but not too much on sunny days. View glazing shades can be automatic or manual.

Effects on Other Systems

- HVAC – No effect on the HVAC system.
- Structural – No effect on the structural system.
- Cost – There will be a minor increase in cost due to the translucent toilet room walls.

Model 16 - Square

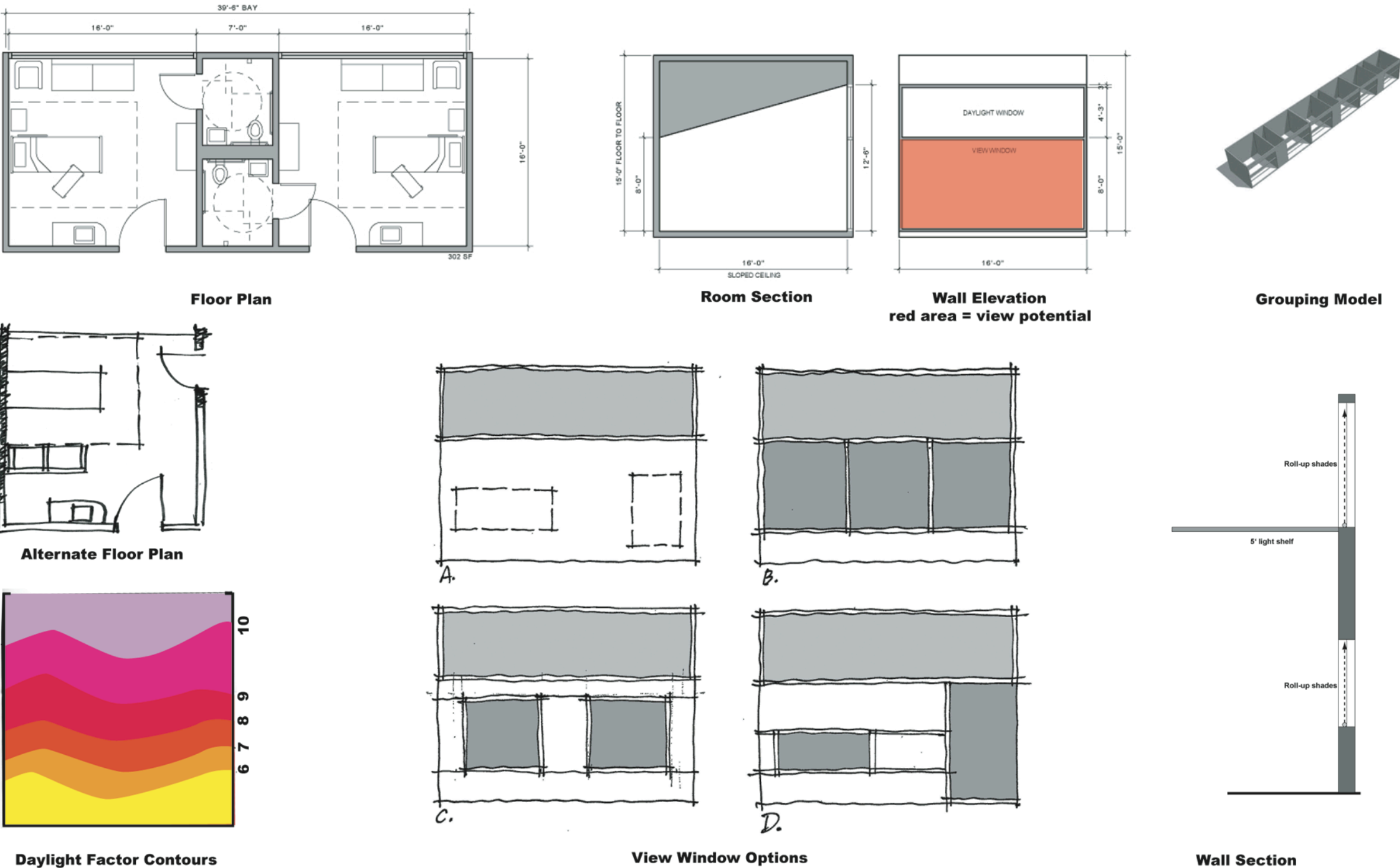


Figure 6 - “Square” configuration (Model 16). View window options are: A) Recommended view apertures from Glare calculations, B) Maximum view window, C) Separated patient view and family view windows as punched openings, D) Separated patient view and family view windows organized as a composition

Performance Evaluation – “Square” (Model 16)

This room design has an equal width and depth of 16', a slanted ceiling allowing for higher window head height and better daylighting performance, and shared-wall toilets. This model has a 15' floor-to-floor height.

Annual Savings

The annual electricity savings for this room is 675 kWh. The electric savings is due to reduced electric light use during daylight hours only. This savings estimate assumes a 0.7 W/sq.ft. power density, a target d.f. of 30 footcandles, and a continuous dimming lighting system. With an electric rate of \$0.045/kWh, the annual savings for this room would be \$30.38.

Well-Being

This design will have a positive effect on patient well-being as it allows for a well-lit room and has a large view potential. The patient will benefit from a close proximity to the windows.

Fenestration

- Size – The daylight window is 4'3" high by 15'6" wide.
- Placement – The daylight window runs along the length of the outer wall, with a sill height of 8' and a head height of 12'3".
- Glazing – Glazing for the daylight window has $V_T=70\%$, $U=0.28$, $SHGC=0.38$. Alternate glazing for the daylight window may be used to reduce visible transmission and heat gain (see Shading below).
- Glare – The glare constant for the daylight window is 52. This is measured from an observation point centered on the daylight window, 10' from the outer wall and 48" from the floor, with the line of sight perpendicular to the outer wall.
- View potential – The view window can be located within an area 7'9" high by 16' wide, for a total view potential of 124 s.f.

Visual Comfort

- The view window is 4' high by 2'6" wide and is centered on the outer wall, with a sill height of 2' and a head height of 6'. Glazing for the view window has $V_T=50\%$, $U=0.25$, $SHGC=0.39$. The view window was sized based on the assumption that the daylight window was not in the field of view (hidden by fixed horizontal blinds or a light shelf) and the adaption level of the viewer was equal to 10 footcandles.
- The maximum glare constant for the combined daylight window and view window should be 150.
- When the patient's visitors are located in front of the view glazing they will be backlit, making it difficult for the patient to see the facial expressions of the visitors.

Shading

The visible transmission through the daylight window must be reduced to 10% in order to achieve the desired illumination goal. A roll-up shade can be used to achieve this goal. Alternately, the use of translucent insulation, such as Kalwall, as the primary glazing for the daylight window can reduce the solar gain and maintain illumination values at a suitable level.

Lighting & Controls

- The electric lights are assumed to be occupancy- and photo-controlled, with manual override.
- The shades on the daylight windows should be motorized or automated. Control of the aperture size is critical to having enough light on overcast days but not too much on sunny days. View glazing shades can be automatic or manual.

Effects on Other Systems

- HVAC – The HVAC ducts will need to be located close to the corridor to accommodate the sloped ceiling.
- Structural – The bay size will have to be relatively large (~32') to accommodate the 16' room width.
- Cost – There will be a minor increase in cost due to the relatively large room size of 256 s.f.

Model 17 - Wide

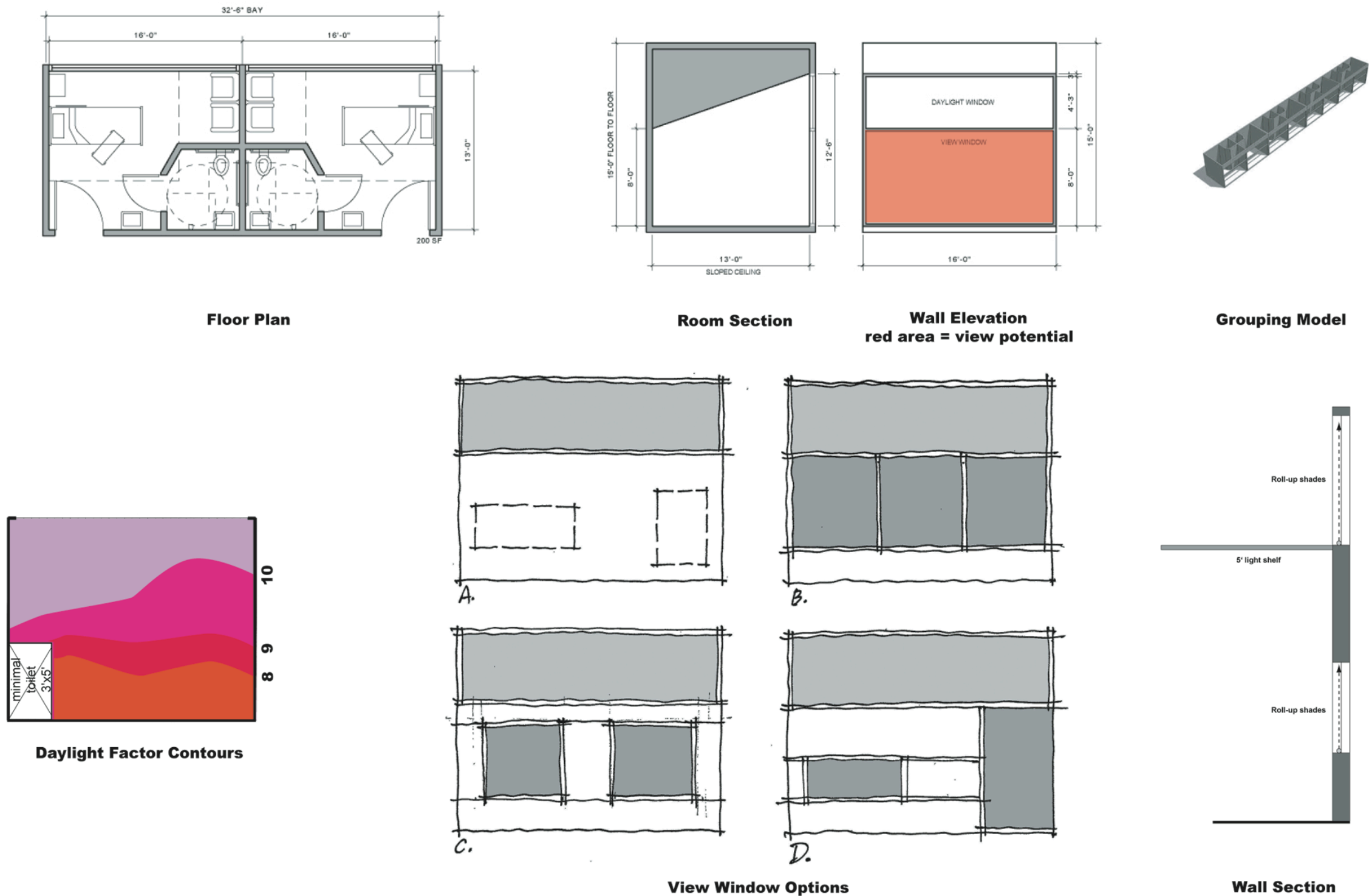


Figure 7 - “Wide” configuration (Model 17). View window options are: A) Recommended view apertures from Glare calculations, B) Maximum view window, C) Separated patient view and family view windows as punched openings, D) Separated patient view and family view windows organized as a composition

Performance Evaluation – “Wide” (Model 17)

This room design is wider than it is deep (16'w x 13'd), allowing for higher daylight values at the back of the room. This effect is enhanced by the high window head heights allowed by the slanted ceiling. This model has a 15' floor-to-floor height.

Annual Savings

The annual electricity savings for this room is 555 kWh. The electric savings is due to reduced electric light use during daylight hours only. This savings estimate assumes a 0.7 W/sq.ft. power density, a target d.f. of 30 footcandles, and a continuous dimming lighting system. With an electric rate of \$0.045/kWh, the annual savings for this room would be \$24.97.

Well-Being

This design will have a positive effect on patient well-being as it allows for a well-lit room and has a large view potential. The patient will benefit from a close proximity to the windows.

Fenestration

- Size – The daylight window is 4'3" high by 15'6" wide.
- Placement – The daylight window runs along the length of the outer wall, with a sill height of 8' and a head height of 12'3".
- Glazing – Glazing for the daylight window has $V_T=70\%$, $U=0.28$, $SHGC=0.38$. Alternate glazing for the daylight window may be used to reduce visible transmission and heat gain (see Shading below).
- Glare – The glare constant for the daylight window is 48. This is measured from an observation point centered on the daylight window, 10' from the outer wall and 48" from the floor, with the line of sight perpendicular to the outer wall.
- View potential – The view window can be located within an area 7'9" high by 16' wide, for a total view potential of 124 s.f.

Visual Comfort

- The view window is 4' high by 2'6" wide and is centered on the outer wall, with a sill height of 2' and a head height of 6'. Glazing for the view window has $V_T=50\%$, $U=0.25$, $SHGC=0.39$. The view window was sized based on the assumptions that the daylight window was not in the field of view (hidden by fixed horizontal blinds or a light shelf) and that the adaption level of the viewer was equal to 10 footcandles.
- The maximum glare constant for the combined daylight window and view window should be 150.
- When the patient's visitors are located in front of the view glazing they will be backlit, making it difficult for the patient to see the facial expressions of the visitors.

Shading

The visible transmission through the daylight window must be reduced to 10% in order to achieve the desired illumination goal. A roll-up shade can be used to achieve this goal. Alternately, the use of translucent insulation, such as Kalwall, as the primary glazing for the daylight window can reduce the solar gain and maintain illumination values at a suitable level.

Lighting & Controls

- The electric lights are assumed to be occupancy- and photo-controlled, with manual override.
- The shades on the daylight windows should be motorized or automated. Control of the aperture size is critical to having enough light on overcast days but not too much on sunny days. View glazing shades can be automatic or manual.

Effects on Other Systems

- HVAC – The HVAC ducts will need to be located close to the corridor to accommodate the sloped ceiling.
- Structural – The bay size will have to be relatively large (~32') to accommodate the 16' room width.
- Cost – There will be a minor increase in cost due to the larger glazing area, but this should be offset by the decreased room size.

Model 23 - Narrow, High Ceiling

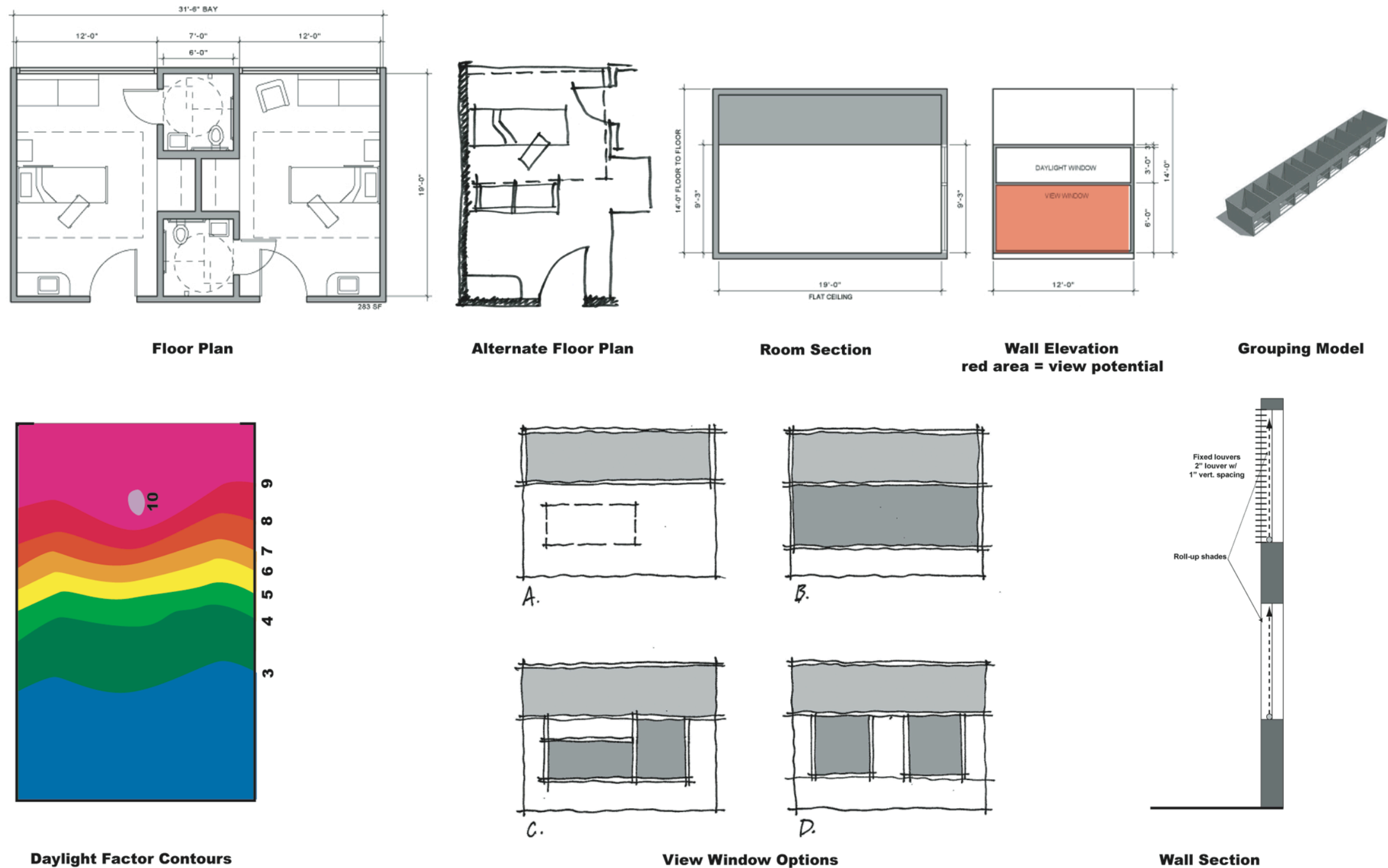


Figure 8 - "Narrow, High Ceiling" configuration (Model 23). View window options are: A) Recommended view apertures from Glare calculations, B) Maximum view window, C) Separated patient view and family view windows as strip windows, D) Separated patient view and family view windows as punched openings.

Performance Evaluation – “Narrow, High Ceiling” (Model 23)

This room design is long and narrow (12'w x 19'd), but has good daylight penetration due to the shared-wall toilets and large daylight glazing afforded by the low sill. This model has a 14' floor-to-floor height.

Annual Savings

The annual electricity savings for this room is 573 kWh. The electric savings is due to reduced electric light use during daylight hours only. This savings estimate assumes a 0.7 W/sq.ft. power density, a target d.f. of 30 footcandles, and a continuous dimming lighting system. With an electric rate of \$0.045/kWh, the annual savings for this room would be \$25.79.

Well-Being

This design will have a positive effect on patient well-being as it allows for a well-lit room and has a large view potential. The patient will benefit from a close proximity to the windows.

Fenestration

- Size – The daylight window is 3' high by 11'6" wide.
- Placement – The daylight window runs along the length of the outer wall, with a sill height of 6' and a head height of 9'.
- Glazing – Glazing for the daylight window has $V_T=70\%$, $U=0.28$, $SHGC=0.38$. Alternate glazing for the daylight window may be used to reduce visible transmission and heat gain (see Shading below).
- Glare – The glare constant for the daylight window is 103. This is measured from an observation point centered on the daylight window, 10' from the outer wall and 48" from the floor, with the line of sight perpendicular to the outer wall.
- View potential – The view window can be located within an area 5'9" high by 12' wide, for a total view potential of 69 s.f.

Visual Comfort

- The view window is 2'6" high by 4' wide and is centered on the outer wall, with a sill height of 3' and a head height of 5'6". Glazing for the view window has $V_T=50\%$, $U=0.25$, $SHGC=0.39$. The view window was sized based on the assumptions that the daylight window was not in the field of view (hidden by fixed horizontal blinds) and that the adaption level of the viewer was equal to 10 footcandles.
- The maximum glare constant for the combined daylight window and view window should be 150.
- When the patient's visitors are located in front of the view glazing they will be backlit, making it difficult for the patient to see the facial expressions of the visitors.

Shading

The visible transmission through the daylight window must be reduced to 10% in order to achieve the desired illumination goal. A roll-up shade can be used to achieve this goal. Alternately, the use of translucent insulation, such as Kalwall, as the primary glazing for the daylight window can reduce the solar gain and maintain illumination values at a suitable level.

Lighting & Controls

- The electric lights are assumed to be occupancy- and photo-controlled, with manual override.
- The shades on the daylight windows should be motorized or automated. Control of the aperture size is critical to having enough light on overcast days but not too much on sunny days. View glazing shades can be automatic or manual.

Effects on Other Systems

- HVAC – The HVAC ducts will need to be altered slightly to accommodate the lower floor-to-floor height.
- Structural – No effect on the structural system.
- Cost – There will be a minor increase in cost due to the increased glazing area, but this should be offset by the lower floor-to-floor height.

Model 26 - Narrow, Low Ceiling

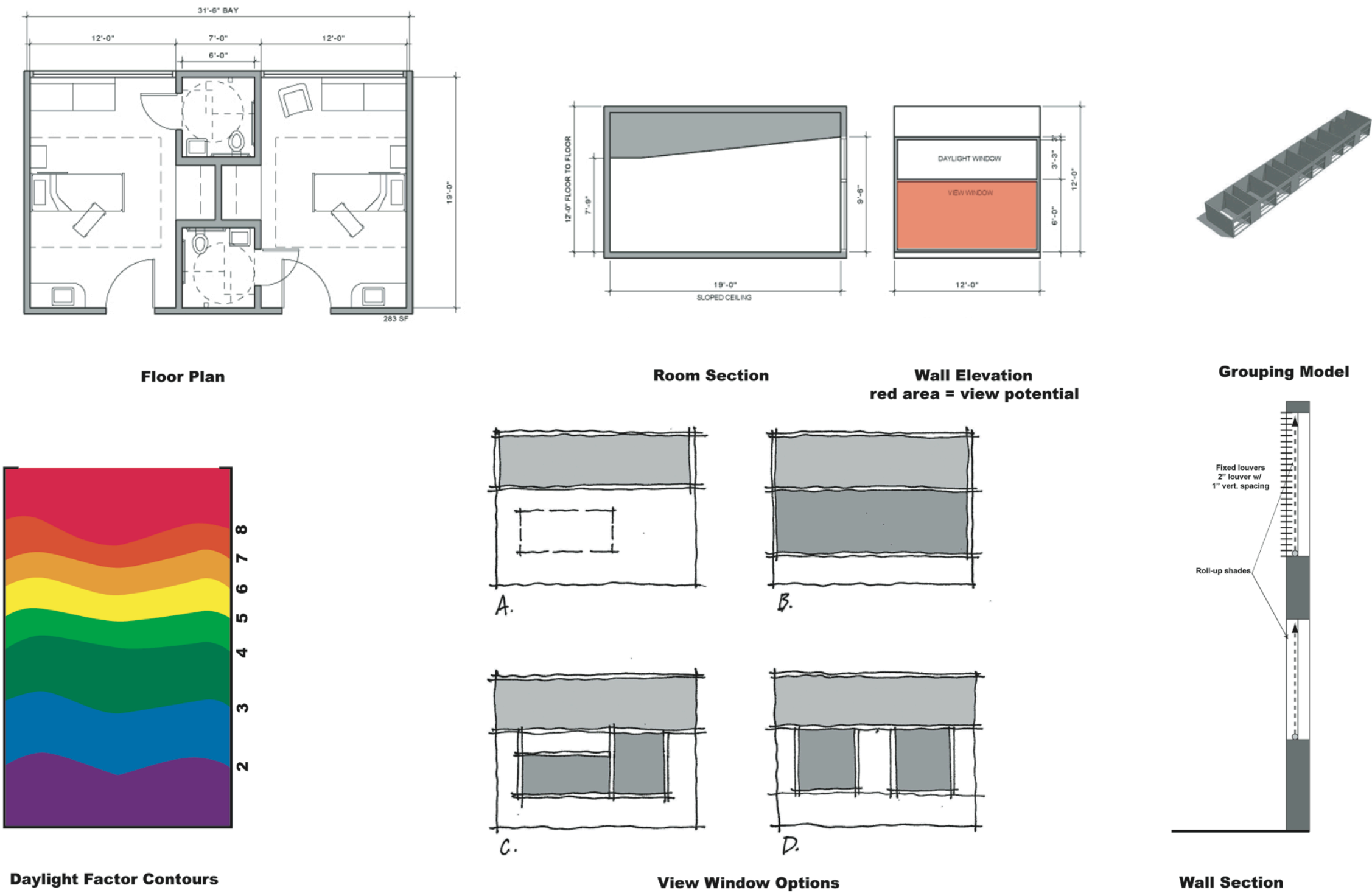


Figure 9 - “Narrow, Low Ceiling” configuration (Model 26). View window options are: A) Recommended view apertures from Glare calculations, B) Maximum view window, C) Separated patient view and family view windows as strip windows, D) Separated patient view and family view windows as punched openings.

Performance Evaluation – “Narrow, Low Ceiling” (Model 26)

This room design is essentially the same as the “Narrow, High Ceiling” configuration, except that it has a more compact 12’ floor-to-floor height. The slanted ceiling allows for a higher window head height, which still permits good daylight in the room.

Annual Savings

The annual electricity savings for this room is 559 kWh. The electric savings is due to reduced electric light use during daylight hours only. This savings estimate assumes a 0.7 W/sq.ft. power density, a target d.f. of 30 footcandles, and a continuous dimming lighting system. With an electric rate of \$0.045/kWh, the annual savings for this room would be \$25.17.

Well-Being

This design will have a positive effect on patient well-being as it allows for a well-lit room and has a large view potential. The patient will benefit from a close proximity to the windows.

Fenestration

- Size – The daylight window is 3’3” high by 11’6” wide.
- Placement – The daylight window runs along the length of the outer wall, with a sill height of 6’ and a head height of 9’3”.
- Glazing – Glazing for the daylight window has $V_T=70\%$, $U=0.28$, $SHGC=0.38$. Alternate glazing for the daylight window may be used to reduce visible transmission and heat gain (see Shading below).
- Glare – The glare constant for the daylight window is 102. This is measured from an observation point centered on the daylight window, 10’ from the outer wall and 48” from the floor, with the line of sight perpendicular to the outer wall.
- View potential – The view window can be located within an area 5’9” high by 12’ wide, for a total view potential of 69 s.f.

Visual Comfort

- The view window is 2’6” high by 4’ wide and is centered on the outer wall, with a sill height of 3’ and a head height of 5’6”. Glazing for the view window has $V_T=50\%$, $U=0.25$, $SHGC=0.39$. The view window was sized based on the assumptions that the daylight window was not in the field of view (hidden by fixed horizontal blinds) and that the adaption level of the viewer was equal to 10 footcandles.
- The maximum glare constant for the combined daylight window and view window should be 150.
- When the patient’s visitors are located in front of the view glazing they will be backlit, making it difficult for the patient to see the facial expressions of the visitors.

Shading

The visible transmission through the daylight window must be reduced to 10% in order to achieve the desired illumination goal. A roll-up shade can be used to achieve this goal. Alternately, the use of translucent insulation, such as Kalwall, as the primary glazing for the daylight window can reduce the solar gain and maintain illumination values at a suitable level.

Lighting & Controls

- The electric lights are assumed to be occupancy- and photo-controlled, with manual override.
- The shades on the daylight windows should be motorized or automated. Control of the aperture size is critical to having enough light on overcast days but not too much on sunny days. View glazing shades can be automatic or manual.

Effects on Other Systems

- HVAC – The HVAC ducts will need major modification to accommodate the sloped ceiling and the relatively low floor-to-floor height.
- Structural – Minor structural changes will be needed to accommodate the low floor-to-floor height.
- Cost – There will be a minor increase in cost due to the HVAC alterations, but this should be offset by the lower floor-to-floor height.

Model 12 - Chevron



Figure 10 - "Chevron" configuration (Model 12). View window options are: A) Recommended view apertures from Glare calculations, B) Maximum view window, C) Separated patient view and family view windows organized as a composition, D) Separated patient view and family view windows as punched openings.

Performance Evaluation – “Chevron” (Model 12)

This room design has a pointed outer wall, which allows for more daylighting and view glazing for an average room width. Similar in features to the “Inboard Typical” model, this room features an inboard toilet that does not obstruct daylight. This model has a 14’ floor-to-floor height.

Annual Savings

The annual electricity savings for this room is 489 kWh. The electric savings is due to reduced electric light use during daylight hours only. This savings estimate assumes a 0.7 W/sq.ft. power density, a target d.f. of 30 footcandles, and a continuous dimming lighting system. With an electric rate of \$0.045/kWh, the annual savings for this room would be \$22.02.

Well-Being

This design will have a positive effect on patient well-being as it allows for a well-lit room and has a large view potential. The patient will benefit from a close proximity to the windows.

Fenestration

- Size – The daylight windows are 1’ high by 8’9” wide.
- Placement – The daylight windows run along the length of the outer walls, with a sill height of 8’ and a head height of 9’.
- Glazing – Glazing for the daylight window has $V_T=70\%$, $U=0.28$, $SHGC=0.38$. Alternate glazing for the daylight windows may be used to reduce visible transmission and heat gain (see Shading below).
- Glare – The glare constant for the daylight windows is 39. This is measured from an observation point centered on the apex of the outer walls, 10’ from the apex and 48” from the floor, with the line of sight perpendicular to the outer wall.
- View potential – The view windows can be located within an area 7’9” high by 18’6” wide (comprising both outer walls), for a total view potential of 143.4 s.f.

Visual Comfort

- The view windows are 4’ high by 2’9” wide. The view windows are located on the outer walls 1’6” from the side walls on either side, with a sill height of 2’ and a head height of 6’. Glazing for the view window has $V_T=50\%$, $U=0.25$, $SHGC=0.39$. The view window was sized based on the assumption that the daylight window was not in the field of view (hidden by fixed horizontal blinds or a light shelf) and the adaption level of the viewer was equal to 10 footcandles.
- The maximum glare constant for the combined daylight windows and view windows should be 150.
- When the patient’s visitors are located in front of the view glazing they will be backlit, making it difficult for the patient to see the facial expressions of the visitors.

Shading

The visible transmission through the daylight window must be reduced to 10% in order to achieve the desired illumination goal. A roll-up shade can be used to achieve this goal.

Alternately, the use of translucent insulation, such as Kalwall, as the primary glazing for the daylight windows can reduce the solar gain and maintain illumination values at a suitable level.

Lighting & Controls

- The electric lights are assumed to be occupancy- and photo-controlled, with manual override.
- The shades on the daylight windows should be motorized or automated. Control of the aperture size is critical to having enough light on overcast days but not too much on sunny days. View glazing shades can be automatic or manual.

Effects on Other Systems

- HVAC – No effect on the HVAC system.
- Structural – No effect on the structural system.
- Cost – There will be a minor increase in cost for the increased glazing area, which should be offset by the decreased floor-to-floor height.

Model 24 - Corner

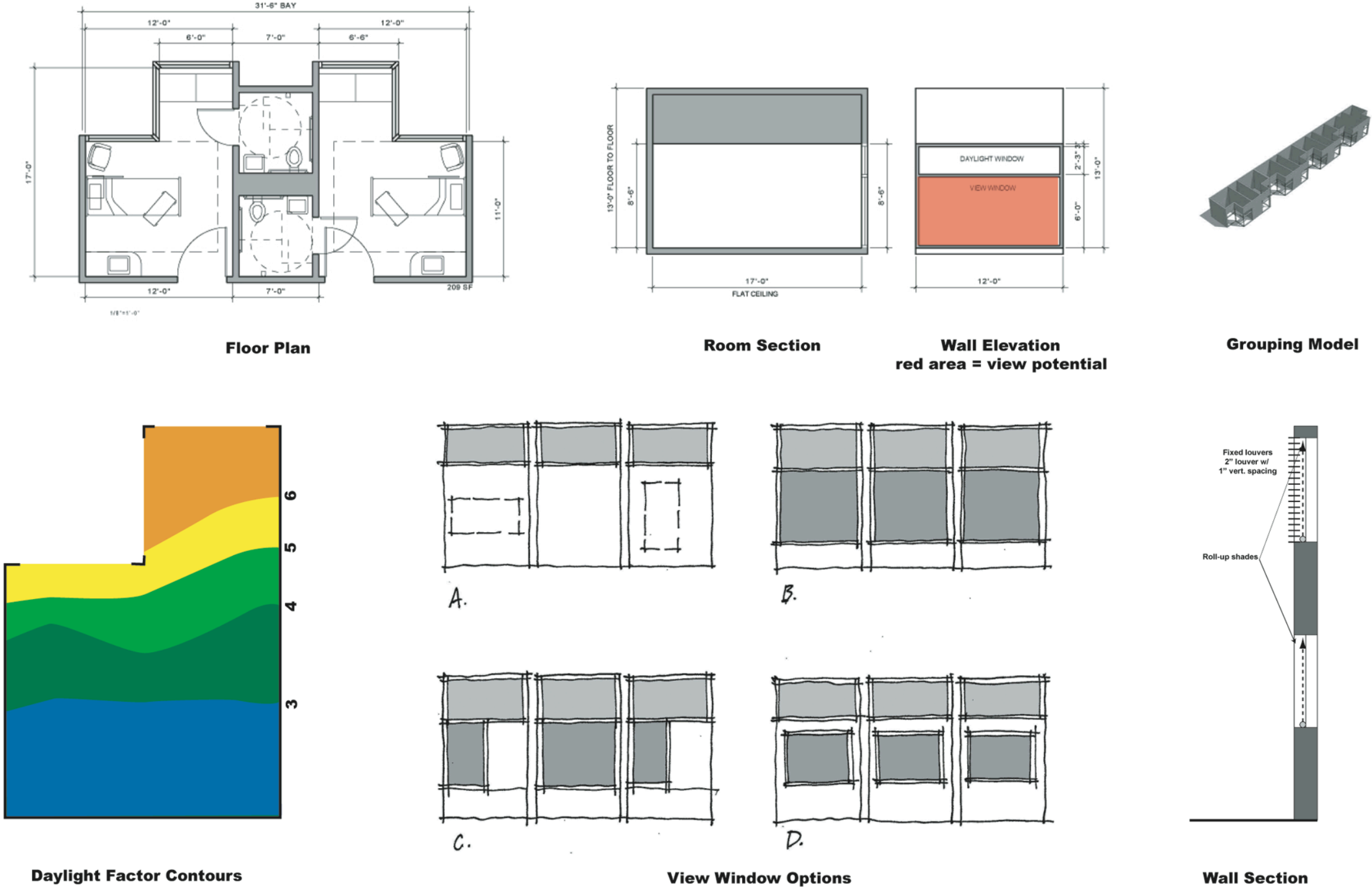


Figure 11 - “Corner” configuration (Model 24). View window options are: A) Recommended view apertures from Glare calculations, B) Maximum view window, C) Separated patient view and family view windows with outside glass corner, D) Separated patient view and family view windows as punched openings

Performance Evaluation – “Corner” (Model 24)

This room design has shared-wall toilets and a notched outer wall, allowing for good daylight distribution throughout the space. This model has a 13' floor-to-floor height.

Annual Savings

The annual electricity savings for this room is 386 kWh. The electric savings is due to reduced electric light use during daylight hours only. This savings estimate assumes a 0.7 W/sq.ft. power density, a target d.f. of 30 footcandles, and a continuous dimming lighting system. With an electric rate of \$0.045/kWh, the annual savings for this room would be \$17.38.

Well-Being

This design will have a positive effect on patient well-being as it allows for a well-lit room and has a large view potential. The patient will benefit from a close proximity to the windows.

Fenestration

- Size – The daylight windows are 2'3" high by 5'6" wide.
- Placement – The daylight windows run along the length of the three outer walls, with a sill height of 6' and a head height of 8'3".
- Glazing – Glazing for the daylight windows has $V_T=70\%$, $U=0.28$, $SHGC=0.38$. Alternate glazing for the daylight windows may be used to reduce visible transmission and heat gain (see Shading below).
- Glare – The glare constant for the daylight windows is 39. This is measured from an observation point centered on the daylight window in the vestibule, 10' from the furthest outer wall and 48" from the floor, with the line of sight perpendicular to the outer walls.
- View potential – The view windows can be located within an area 5'9" high by 18' wide (comprising three outer walls), for a total view potential of 103.5 s.f.

Visual Comfort

- The view windows are 3'6" high by 2'6" wide. They are centered on the two outward-facing walls (those parallel to the corridor), with a sill height of 2'6" and a head height of 6'. Glazing for the view windows has $V_T=50\%$, $U=0.25$, $SHGC=0.39$. The view windows were sized based on the assumptions that the daylight windows were not in the field of view (hidden by fixed horizontal blinds) and that the adaption level of the viewer was equal to 10 footcandles.
- The maximum glare constant for the combined daylight windows and view windows should be 150.
- When the patient's visitors are located in front of the view glazing they will be backlit, making it difficult for the patient to see the facial expressions of the visitors.

Shading

The visible transmission through the daylight window must be reduced to 10% in order to achieve the desired illumination goal. A roll-up shade can be used to achieve this goal. Alternately, the use of translucent insulation, such as Kalwall, as the primary glazing for the daylight windows can reduce the solar gain and maintain illumination values at a suitable level.

Lighting & Controls

- The electric lights are assumed to be occupancy- and photo-controlled, with manual override.
- The shades on the daylight windows should be motorized or automated. Control of the aperture size is critical to having enough light on overcast days but not too much on sunny days. View glazing shades can be automatic or manual.

Effects on Other Systems

- HVAC – There will be minor modifications to the HVAC ducts due to the low floor-to-floor height.
- Structural – No effect on the structural system.
- Cost – There will be a minor increase in cost due to the larger glazing area, but this should be offset by the lower floor-to-floor height.

Model 28 - Diagonal Champ

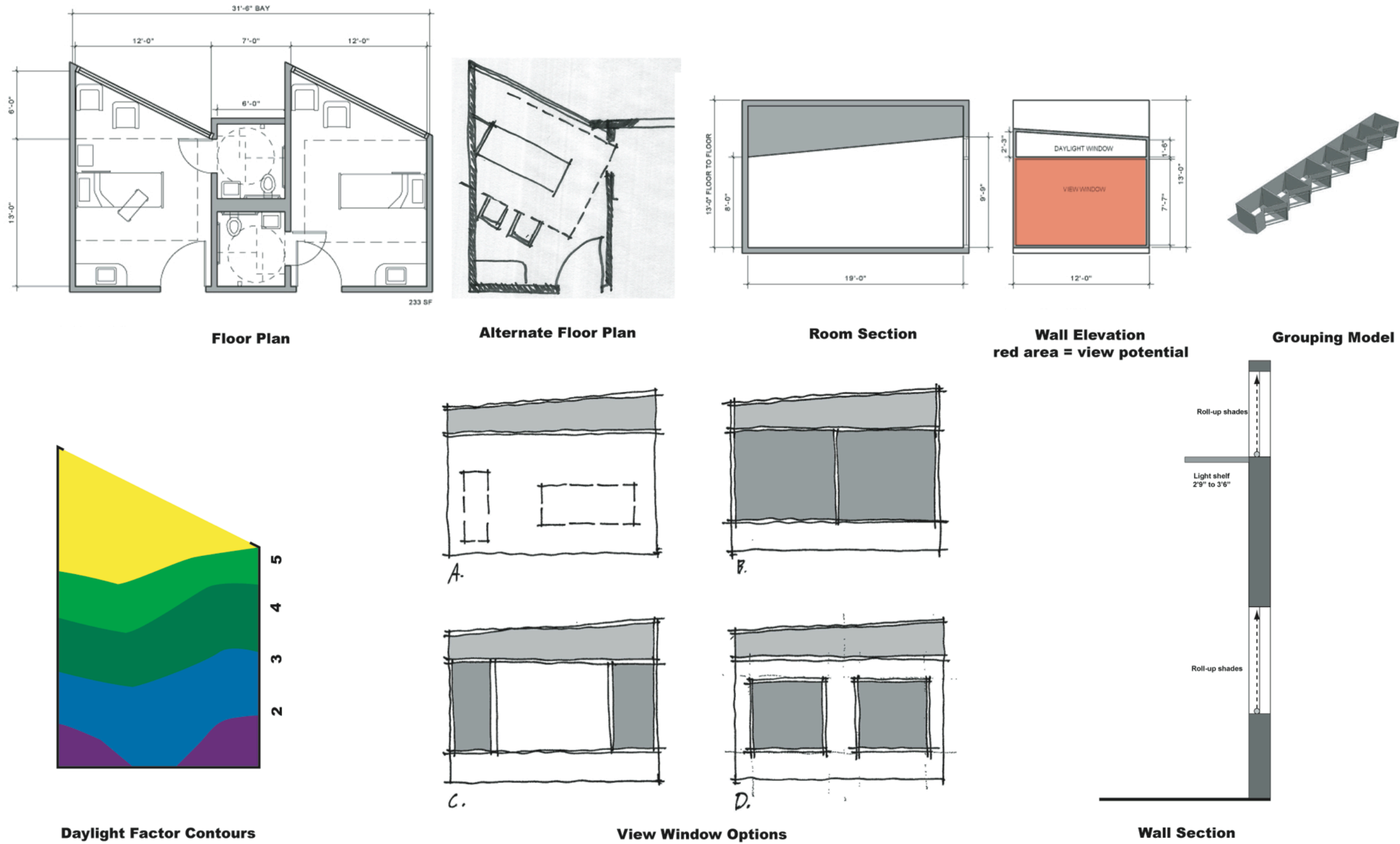


Figure 12 - “Diagonal Champ” configuration (Model 28). View window options are: A) Recommended view apertures from Glare calculations, B) Maximum view window, C) Separated patient view and family view windows paired with adjacent room windows, C) Separated patient view and family view windows as punched openings

Performance Evaluation – “Diagonal Champ” (Model 28)

This was the top-ranking design for daylight distribution. The room features a slanted outer wall and slanted ceiling, with shared-wall toilets. This model has a 13' floor-to-floor height.

Annual Savings

The annual electricity savings for this room is 424 kWh. The electric savings is due to reduced electric light use during daylight hours only. This savings estimate assumes a 0.7 W/sq.ft. power density, a target d.f. of 30 footcandles, and a continuous dimming lighting system. With an electric rate of \$0.045/kWh, the annual savings for this room would be \$19.07.

Well-Being

This design will have a positive effect on patient well-being as it allows for a well-lit room and has a large view potential. The patient will benefit from a close proximity to the windows.

Fenestration

- Size – The daylight window is an average 1'10.5" high by 13' wide.
- Placement – The daylight window runs along the length of the outer wall, with a sill height of 8' and a head height of 1'6" high at one end and 2'3" high at the other (trapezoid shape).
- Glazing – Glazing for the daylight window has $V_T=70\%$, $U=0.28$, $SHGC=0.38$. Alternate glazing for the daylight window may be used to reduce visible transmission and heat gain (see Shading below).
- Glare – The glare constant for the daylight window is 31. This is measured from an observation point centered on the daylight window, 10' from the outer wall and 48" from the floor, with the line of sight perpendicular to the outer wall.
- View potential – The view windows can be located within an area 7'9" high by 13'9" wide, for a total view potential of 106.4 s.f.

Visual Comfort

- The view window is 4' high by 3'3" wide. It is located on the outer wall, 1'6" from the short edge, with a sill height of 2' and a head height of 6'. Glazing for the view window has $V_T=50\%$, $U=0.25$, $SHGC=0.39$. The view window was sized based on the assumptions that the daylight window was not in the field of view (hidden by fixed horizontal blinds or a light shelf) and that the adaption level of the viewer was equal to 10 footcandles.
- The maximum glare constant for the combined daylight window and view window should be 150.
- When the patient's visitors are located in front of the view glazing they will be backlit, making it difficult for the patient to see the facial expressions of the visitors.

Shading

The visible transmission through the daylight window must be reduced to 10% in order to achieve the desired illumination goal. A roll-up shade can be used to achieve this goal.

Alternately, the use of translucent insulation, such as Kalwall, as the primary glazing for the daylight window can reduce the solar gain and maintain illumination values at a suitable level.

Lighting & Controls

- The electric lights are assumed to be occupancy- and photo-controlled, with manual override.
- The shades on the daylight windows should be motorized or automated. Control of the aperture size is critical to having enough light on overcast days but not too much on sunny days. View glazing shades can be automatic or manual.

Effects on Other Systems

- HVAC – There will be minor modifications to the HVAC ducts due to the low floor-to-floor height and the sloped ceiling.
- Structural – No effect on the structural system.
- Cost – There will be a minor increase in cost due to the increased glazing area, but this should be offset by the lower floor-to-floor height.

1.0 INTRODUCTION

For this report, we surveyed current research and practices in the field of healthcare facility design. Based on that information, an initial list of room form-related characteristics was compiled (e.g. room depth, room width, ceiling height). These characteristics were then analyzed to determine their relative importance and to narrow the range of each characteristic for physical testing. A number of models were then physically tested and analyzed to provide data on the effects of these characteristics on daylighting. Based on these tests, guidelines for design were developed. Issues of room aggregation and unit design were not considered as it was felt that this level of inquiry exceeded the scope of the project.

1.1 THE IMPORTANCE OF DAYLIGHT

Daylighting is the strategy of using architectural form to provide light to the interior spaces of a building. Historically, the need to introduce and distribute daylight within interior spaces was a major determinant of architectural form. However, daylighting as a primary strategy had diminished by the middle of the 20th century due to the development of building environmental control and electric lighting systems technologies, coupled with the availability of relatively cheap energy. This has been particularly true with institutions such as hospitals. The boom in hospital construction following World War II, which coincided with advances in medical technology and an increased concern with hygiene and sterility resulted in hermetically sealed buildings, frequently with limited access to daylight.

Increasing energy costs as well as increasing public awareness of the environmental and social costs of energy production is reversing this trend. The energy and cost savings afforded by daylighting strategies is now enjoying increased attention, and for large institutional buildings these savings can be substantial. For hospitals, an additional concern that has prompted a renewed interest in daylighting is that of patient well-being. There is some evidence that the psychological benefits of providing patients with access to daylight and views may hasten their recuperation and shorten their hospital stay.

1.2 CASES AND EXAMPLES FROM CURRENT PRACTICE

Universal Room Design

One of the most significant trends in hospital design is that of the universal room design. Recent trends in managed healthcare have led to a notable increase in ambulatory care centers and outpatient care facilities (Nesmith, 1995, p. 9). Consequently, those patients who require hospitalization typically have more acute health problems than hospital inpatients a decade ago. This has led to the need for newly constructed medical facilities to allow most patient rooms to have critical care capabilities. At this point in time, with baby boomers nearing their senior years and outpatient services becoming so popular, it is vital to give newly constructed patient rooms the flexibility to be converted from an acute care room to a critical care room with limited

renovation (Nesmith, 1995, p. 10). Trends indicate that virtually all patients in the future who are housed in acute care hospitals will require a level of care close to intensive care, with sophisticated monitoring.

The “universal room” concept requires a room to be designed so that it may be converted from an acute care room to an intensive care unit (ICU) room in a very short time with very little remodeling. ICU rooms have larger breakaway folding doors, require larger clearances around the bed, and require a visual connection (such as an internal window) between the patient and the caregiver area outside the room. These requirements are achieved through the use of flexible long-span structures, with vertical service systems pulled out of the core to leave the floor plate as free as possible for change. Also, the universal room concept typically only works with outboard or shared-wall toilet room configurations. All of these structural and layout requirements for the universal room design can affect the potential for fenestration and daylighting.

There is only one requirement for interior glazing as well. To accommodate both acute care and intensive care functions, openings/glazing from the patient room to the corridor must “allow visibility of the patient from the staff work space.” While this requirement does not specify the size of the opening, current standards of practice have increased the standard openings in ICU rooms to two 4’ break-away sliding glass doors for an overall opening 8’ wide by 8’ to 9’ high.

Access To Daylight

The location of the building site is one of the most important factors affecting potential access to daylight in the patient room. The site orientation, geography, site context (existing buildings and other obstructions), and regulations regarding setbacks and height can all have a major effect on the ability to daylight patient rooms.

The site limitations may directly affect some of the factors illustrated in Figure 1. For example, a constrained urban site may limit the unit size, shape and orientation of the clusters of rooms. Accepted norms in nursing unit design steer the design to wards having rooms on the perimeter and support spaces in the middle. A site that requires a small building footprint can restrict unit orientations and may not allow for the best daylighting for the patient rooms. Similarly, municipal height restrictions may limit the floor-to-floor height.

Such site-related limitations consequently affect how the rooms are designed, potentially limiting factors such as the bay size, the ceiling height, and the toilet location. All of these will in turn affect the size and location of the glazing, and therefore the daylighting potential.

Structure & HVAC

The typical structure for a high-rise health care building is a tower with beams and columns. The layout is configured with two rooms per bay, which usually forces an edge beam condition. The presence of an edge beam can be problematic in daylighting as it limits the daylight window head height and consequently the daylight penetration. There are, however, some structural options that may reduce or eliminate the edge beam:

Load-Bearing Walls

These are load-bearing walls that separate the rooms and the floor decking, spanning from wall to wall. This type of structure can be difficult for high-rise construction and severely limits or eliminates future flexibility. An advantage of this system is that it allows for floor-to-floor glazing, but this type of concrete construction takes longer.

Post-Tensioned Slab

Using a post-tensioned slab may eliminate the end beam condition. However, it results in slower construction time for concrete construction. There may also be a minor reduction in future flexibility in floor penetrations, but this can be addressed by filling the tendon cavity with grout. As with the load-bearing wall system, this type of structure allows for floor-to-floor glazing.

Upturned Perimeter Beam

Some of the restrictive problems inherent in the perimeter beam may be avoided by upturning the edge beam in steel and concrete structural systems. This results in a more complex steel detailing, and greater cost, but provides a larger perimeter opening.

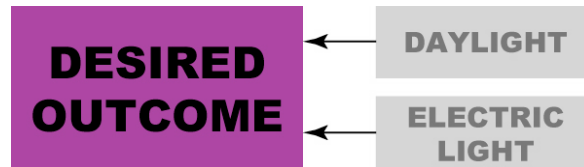
Hollow Core Precast Concrete Planks

These hollow planks are 10"-12" thick and require a 2" topping slab. They can span from beam to beam (30' +/-). The edge beam is replaced with an upturned steel angle. This 14" composite is much thinner than a typical perimeter beam of 18"-24". One drawback to this system is that using concrete planks and a topping slab is not regularly cost competitive and may limit future flexibility. However, it does allow for quick erection and provides a larger perimeter opening.

The perimeter HVAC edge duct is typically used as a return air duct. In addition, a radiant fin tube is used at the base of the perimeter window. This duct and its register that blows into the room can be as far away from the window as 10'. Combining the perimeter duct with the light shelf creates difficulties at the end of the duct runs with routing the duct back up to the ceiling plenum.

2.0 FACTORS THAT AFFECT DAYLIGHTING AND PATIENT WELL-BEING

The factors that govern the daylighting of patient rooms and their effect on patient well-being have a number of interactions that affect their potential results. This section expands on the ideas covered in the introductory section, giving details about the mechanisms that affect daylighting and how they interact, and explaining how daylighting and views affect the psychological state of the patient.



2.1 POTENTIAL EFFECTS OF DAYLIGHT AND VIEW WINDOWS ON ENERGY CONSERVATION

The windows that allow light in and out of the room also act as conduits for thermal heat flow. The primary forms of heat transfer through windows are solar heat gains into the space and heat gains and losses via conduction based on the temperature differential between the inside and outside. These unwanted heat gains or losses are dictated by the size of the windows and their energy and thermal properties, such as the insulation characteristics (R-value), visible light transmission factor (V_T), and the solar heat gain coefficient (SHGC). Consequently, fenestration can represent an energy conservation liability in that there is the potential for increased cooling costs during warm months and increased heating costs during cold months.

However, because lighting represents the single largest energy usage for health care facilities, accounting for nearly a third of the energy used in the building, the benefits of daylighting hospital rooms can outweigh the liabilities of unwanted heat transfer (see Figure 13). The most prevalent relationship between fenestration and energy consumption is the reduction in use of electric lighting. When daylighting is used to reduce the use of electric lighting, savings can be as high as 57% during daylight hours (assuming a daylight factor of 2, a target illumination of 30 footcandles and a continuous dimming system). Note that hospitals operate on a around-the-clock schedule and that electric savings will be realized only during daylight hours. Consequently, only half of the lighting “wedge” in Figure 13 would be affected.

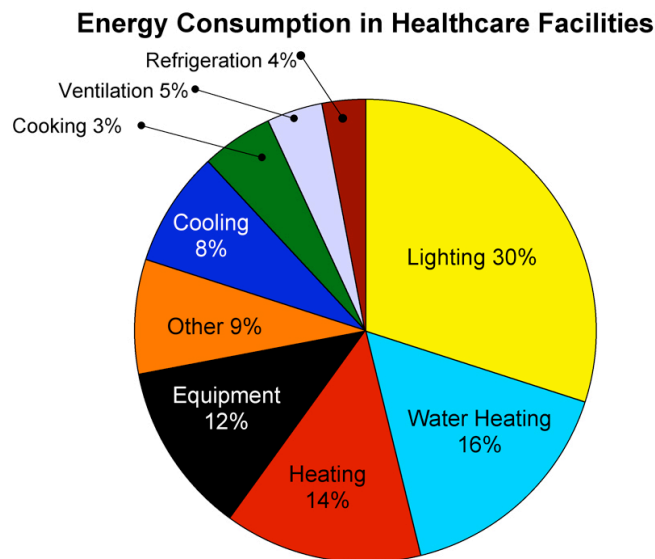


Figure 13 - Energy consumption in healthcare facilities (Carmody, et al, p. 32)

2.2 PSYCHOLOGICAL WELL-BEING

Along with energy savings, an important goal of good hospital room fenestration design is to increase the well-being of the patient. Patient well-being can be defined as the psychological states that result in reduced stress and anxiety, lower blood pressure, improved post-operative recovery, reduced need for pain medication, and shorter hospital stays. A number of studies have indicated that a room design that allows for good views and daylighting will result in increased patient well-being. Researcher Roger Ulrich states that three factors positively affect patient well-being: access to support, a sense of control, and access to positive distractions (Ulrich, 1992, p. 23). Of these, the latter is of particular interest to this study. Access to positive distractions can be directly linked to factors such as good daylighting and proper design of view fenestration.

Benefits of Daylight

There are a number of important biological functions for which daylight is an important factor. For example, not having a regular daily circadian rhythm due to lack of exposure to daylight (and night) has been shown to have adverse health effects (Noell-Waggoner, p. 4). Daylight is also necessary for the body's synthesis of serum Vitamin D, which is essential for the absorption of calcium by bones and tissue. Vitamin D is synthesized in the skin during exposure to ultraviolet B (UVB) radiation, but most types of indoor lighting do not emit UVB radiation. For many patients, daylight therefore becomes the main source for Vitamin D (Ibid., p. 2).

Daylight has a proven antiseptic effect as well, helping control infections. Ambient respiratory microorganisms, when coughed or sneezed into the air, may remain infectious for days or even weeks. These microorganisms are able to travel a considerable distance from their source via air currents. Experiments and clinical evidence have demonstrated that daylight, even from overcast skies, is an effective lethal agent to these airborne microorganisms (Rosenfield, 1945, p. 95).

Daylight has also been shown to have a positive effect on psychological states and relaxation. A study was done on 40 office workers that demonstrated a connection between their psychological state and the ratio of daylit floor area to total floor area. Based on the results of this study, the researchers were able to calculate an index of relaxation based on the daylit floor area ratio. The study found that the daylit floor area ratio had a positive effect on relaxation at levels below 40%, with a maximum relaxation level around 20% (Boubekri, et al, p. 487). This would seem to indicate that the presence of daylight in a hospital room would provide a psychological benefit in addition to the physiological advantages mentioned.

In addition, monetary savings can be obtained by improving the recovery time of patients, and the psychological well-being afforded by proper daylighting and view potential has been shown to shorten the stay of patients by approximately 10% (Ulrich, 1984, p. 420). This can result in a lower overall number of patients in the facility at any given time if the hospital is not fully occupied, with attendant operational and energy savings. Hospitals tend to be more profitable when the patients recover more quickly (Flanagan, p. 67).

Benefits of Good Views

A patient room gives its occupants the potential to access views for psychological well-being by being composed of at least one exterior wall. What the views consist of depends on the site orientation, building composition, and general surroundings. Patient well-being, and consequent healthcare outcome, is improved with fenestration that provides adequate views. Researcher Stephen Verderber cites that the best view is a passive nature scene, one that contains the three primary elements of ground, inanimate objects (trees, buildings, mountains, etc.), and sky (Verderber, 1986, p. 454).

A link has been demonstrated between view-related psychological well-being and recovery rate. Ulrich studied the records of a number of different patients recovering from the same surgical procedures in a wing of a suburban Philadelphia hospital. All of the rooms were identical, except that half of them looked out on a small stand of deciduous trees, while the other half looked out on a brick wall. Figure 14 shows a plan of the rooms in this study. Ulrich found that patients with the nature view had statistically significant shorter recovery times and lower consumption of narcotic painkilling drugs (Ulrich, 1984, p. 421).

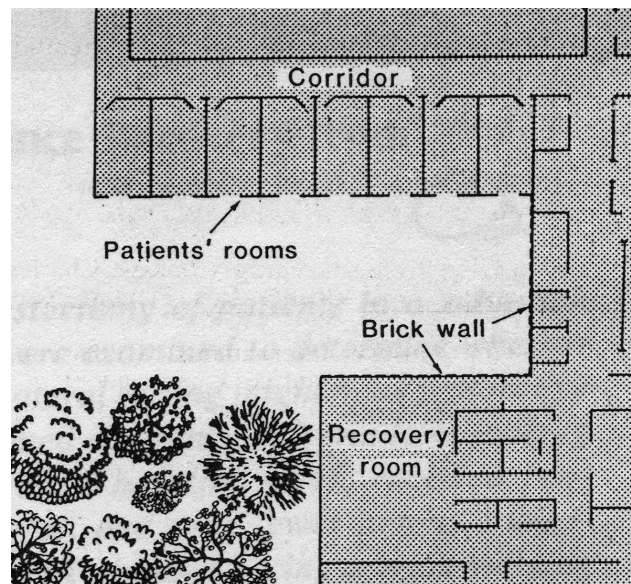


Figure 14 - Room layouts for Ulrich's view study. (Ulrich, 1984, p. 421)

Verderber has conducted a number of studies on the therapeutic effects of windows in the hospital environment. His index of “windowness” is a measure of the exposure to a window view and is based on exposure time, window size, sill height, view complexity, proximity and use of external shades. Based on studies of patients in six Chicago hospitals, Verderber was able to ascertain a positive correlation between patients’ “windowness” and their psychological state and recovery time. Interestingly enough, his results showed that a meaningful view through a window was more important than good sunlight transmission. On a list of thirteen attributes, sunlight transmission ranked fourth, after meaningful views, views of street life, and perceptual access (Verderber, 1982, pp. 476-492).



2.3 DAYLIGHT

In this study, daylight is evaluated using the daylight factor (d.f.), which is the ratio of the illumination inside a space to the illumination available outside. The daylight factor is comprised of three components: the sky component (SC), the internally reflected component (IRC), and the externally reflected component (ERC). The SC is a result of the illumination directly from the sky on the spot where the d.f. is measured. The IRC results from light reflecting off objects inside the space such as walls, ceiling, and furniture. The ERC results from light reflecting off objects outside of the space, such as nearby buildings and pavement. Given that the external context of the rooms in this study is an unknown, the ERC was not incorporated into any calculations.

Light Levels and Distribution

The amount of daylight available in a given space depends on two primary components: the direct sky component, which is determined primarily by the size and position of the windows, and the internally reflected component (IRC), which is determined largely by the reflectivity values of the surfaces and objects in the space. Often, the IRC will have a greater effect on the overall daylight illumination levels than does the direct sky component. Obstructions – both external and internal – also have an effect on the daylight distribution of a space.

A variety of activities take place within a patient room, requiring various levels of lighting. For example, a medical examination typically requires higher illumination levels than those needed for a patient to read in bed. The IESNA Lighting Handbook gives the following guidelines for illumination of activities in healthcare facility patient rooms:

Activity	Horizontal Illumination	Vertical Illumination
General	5 fc	3 fc
Observation	3 fc	3 fc
Critical examination	50 fc	10 fc
Reading	30 fc	5 fc
Toilets	30 fc	3 fc

Figure 15 - IESNA recommended illumination values for healthcare patient rooms

It is also important to consider that many of the residents of hospital rooms tend to be older, or have acute health problems. Special consideration needs to be taken for lighting with regards to

the elderly, as physiological changes take place in the eye with aging. For example, glare is an important issue for the elderly as their eyes do not adjust as quickly to changes in lighting levels. Consequently, a maximum luminance ratio of 10:1 is recommended to avoid excessive glare (IESNA RP-28-98, p. 13).

Glare

In the context of daylighting, glare occurs when there is a strong contrast in luminance between the window and the field of view within the room. The human eye adapts quickly to the average brightness in the field of vision, but it is also drawn to the source of highest luminance in that field. This would be the case, for example, of a visitor in a hospital room whose field of view includes a window. If the visitor's object of attention is the patient or another object in the field of view other than the window, several adaptation problems may occur:

- The visitor's eyes adapt to the higher luminance levels of the window, thus reducing the relative brightness of the patient or other object of attention and making it more difficult to see.
- The visitor's eyes are simultaneously drawn to the patient and the window, causing visual discomfort.
- The visitor's eyes constantly vary their adaptation level as they change their attention between the patient and the glare source at the window.

These hold true even when the sky luminance is relatively low, as the perceived glare and discomfort is proportional to the solid angle apprehended by the viewer. Consequently, a large low-luminance source such as a window will often result in more visual discomfort than a small, bright point source such as a task light.

Glare is therefore a product of where the window is placed in the wall, the direction the window faces, the type of glazing, and the type and amount of shading available. Hospital patients often have limited mobility and spend the majority of their time in bed. Sunlight directed into the eyes or onto a television screen causes added stress to the patient. For caregivers, glare might not only be a nuisance, but also a hindrance to productivity. Many types of medical equipment have bedside monitors or touch screens that can be obscured by reflections or bright direct light.

These conditions may cause the patient or caregiver to close the blinds, eliminating natural views and cutting off exposure to direct daylight. By separating the view window and the daylight window and their shading devices, the source of glare (usually the view window) can be cut off while still allowing daylight into the room. Additionally, using a semi-transparent shade cloth with V_T values ranging from 2% to 18% on the view window can also help reduce glare while retaining outside views. Similarly, roll-up blinds of opaque material can be used to reduce the effective aperture size by any desired amount.

View Potential

Views of nature provide patients with a positive distraction from their surroundings and give them some sense of what is happening in the "outside world." Views of natural settings have been found to have positive effects in a variety of settings. For example, one study indicated that blood donors who viewed videotapes of natural environments had lower stress levels than those

who viewed urban scenes. These patients on average had pulse rates that were 3% lower and diastolic blood pressures that were 1% lower than those patients who viewed the urban scene (Ulrich et al, 2003, p. 44). “In hospitals, the representation of nature – be it ocean, sky, or forest – appears to help satisfy human informational needs” (Verderber, 1986, p. 459). Windows with three-layer views of ground, urban inanimate objects, and sky satisfy the human need for information, thus promoting calm and relaxation (Verderber, 1982, p. 482).

A great deal of what has been discussed regarding patient psychological well-being has been related to the view from the patient room. Research by Ulrich, Verderber and others has established a link between view and psychological well-being. Jay Appleton has developed the *prospect-refuge theory*, which states that the ability to view (prospect) without being exposed to others’ observation (refuge) has a strong effect on the viewer’s psychological state. He postulates that this harkens back to primitive behavior in which creatures engaged in hunting or being hunted have an environmental advantage in positioning themselves in a place where they can

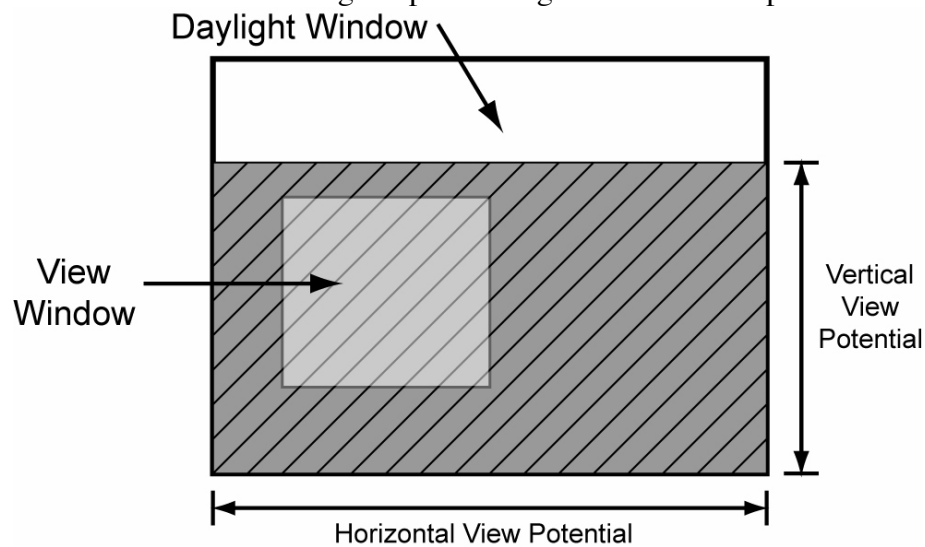


Figure 16 - External wall showing daylight window and view window

view the surrounding area without being visible, such as in the tree line at the edge of a clearing (Appleton, pp. 65-66). Aesthetic pleasure in viewing the landscape derives from the observer experiencing an environment that satisfies his or her biological needs. The ability to see without being seen is a step towards satisfying those needs; the capacity of an environment to ensure the achievement of this becomes an immediate source of aesthetic satisfaction and, by extension, psychological well-being.

The perception of the quality of the view is strongly influenced by the size of the aperture and the viewer’s distance from it. For a fixed window size, the closer the viewer is to the window, the larger the available scope of view. For example, in a study using a window 5’ wide and 10’ high, the scope of view increases 350% when the viewpoint moves from 10’ from the window to 5’ from the window (Zeng, p. 8). For a given scope of view, then, the closer the viewer is to the window, the smaller the required window size to obtain that scope of view. For example, a scope

of view obtained by a window 2.5' wide by 5' high from a distance of 10' can be obtained by a window 1.5' wide by 3' high at a 5' distance (Ibid., p. 10). In other words, by moving the viewpoint from 10' from the wall to 5' from the wall, the window size can be reduced 64% to obtain the same scope of view. These concepts are illustrated in Figure 17.

Thus, if the patient is located closer to the window, a smaller window will be able to provide an adequate view. The placement of the view window in relation to the patient also has a strong effect on the view and the potential well-being derived. This is particularly true of the relative location of the window head and sill, which should be positioned to give the patient a good view of both the ground plane and the sky in order to achieve Verderber's recommended three primary elements of ground, inanimate and animate objects, and sky. The sill height is important in determining the scope of view, particularly in tall buildings. In order to provide a view of a fixed scene on the ground plane, the view window sill must be lower for rooms higher in the building (Ibid., p. 16). This concept is illustrated in Figure 18. Note that the maximum prescribed sill height for hospital patient rooms is 36". While this should be adequate to provide Verderber's recommended view elements for many buildings, it may be necessary to use smaller sill heights in high-rise hospitals.

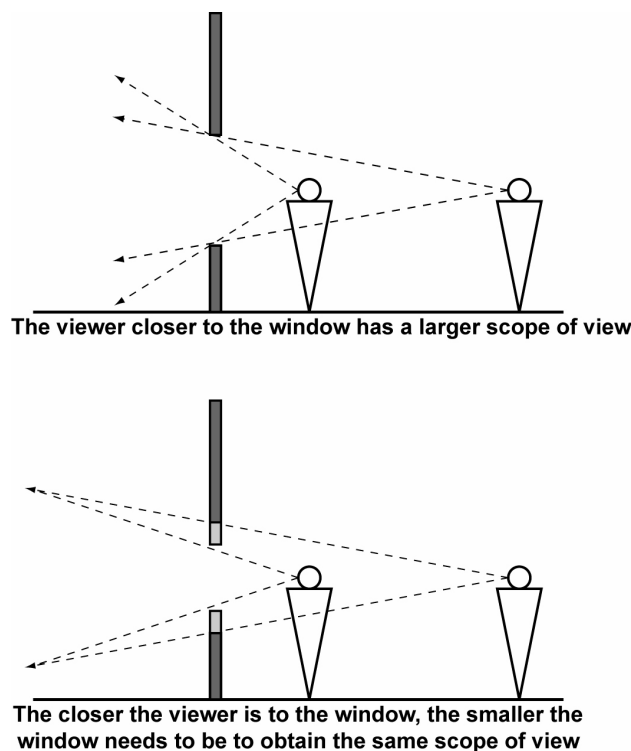


Figure 17 - Relationship between the viewer distance to the window, the scope of view and the window size

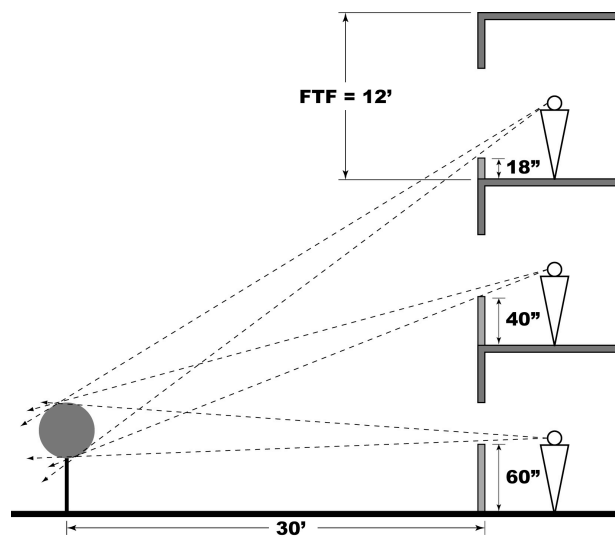


Figure 18 - Relationship between sill height and fixed scope of view

Another factor to consider when determining the size and placement of view windows is the eye level of the observer. The average standing eye level for adults is 62", and for seated adults it is 47" (Zeng, p. 24). However, the designer should focus on the eye level of the reclining patient, which for an average bed is 30". However, it should be noted that many hospital beds can be raised and tilted so that the patient's eye level may be in excess of 60".

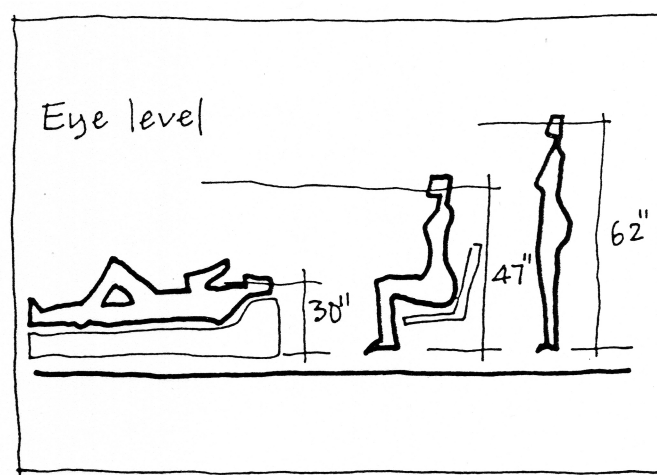


Figure 19 - Average adult eye levels for reclining in bed, sitting, and standing positions (from Zeng, p. 25)

Techniques for evaluating the view are somewhat limited. One solution is to measure the view through the window from the patient's vantage point as a solid angle (in steradians). Carmody and Selkowitz propose a *view index*, which is the product of the window area, the visible transmittance (V_T), the fraction of the window area not obstructed by fixed exterior shading devices and the percentage of the time that the view is not obstructed by interior shades

(Carmody, et al, p. 49). Verderber's measure, called "windowness," is a metric based on window/wall ratio, sill height, view complexity, proximity to window, screen use, and amount of exposure or viewing time (Verderber, 1982, p. 481).

For the sake of this study, we will quantify the view with the term "view potential," which we will define as the total area of exterior wall space not being taken up by daylight fenestration. Unlike the metrics discussed previously, the view potential gives a measure of the area available for the placement of the view windows. The larger the view potential area, the more latitude the designer has in sizing and locating the view windows to increase the patients' well-being. Figure 16 shows a representation of the view potential concept.



2.4 ELECTRIC LIGHT

Electric Lighting Configuration

For patient rooms, there may be as many as 10 different major and minor zones for lighting. The typical power density for lighting in a patient room is between 0.6 and 0.8 watts per square foot. The primary types of electric lighting are task lighting, which is typically of high wattage and used for short durations (e.g. physical exams), and ambient lighting. Ambient lighting integrates readily with daylighting, particularly if the ambient light has an indirect lighting fixture.

Controls

There is evidence that if patients have a sense of control over their healing environment it leads to quicker recovery (Ulrich in Marberry, 1995). This can be as simple as providing bedside controls to lighting, television, and window shades. Regardless of how a room is designed, just having the power to manipulate the environment contributes to a patient's psychological outlook, rate of healing, and quality of stay (Ulrich, 1992, p. 23). Patient control over lighting, temperature and/or shading from the patient bed is a factor in access to daylight. Designers should strive to find a balance between allowing patient control and designing for adequate daylighting. There should be automatic controls that integrate the electric lighting with the daylighting. A light sensor and continuous or step dimmer can be used to maintain the ambient illumination levels at a constant value based on the amount of daylight in the space. Hospital rooms are typically divided into two or three major lighting zones, which may or may not correspond to the occupancy zones (see Section 2.6). The closer the lighting zone is to the window, the more daylight it will receive. We recommend a system for ambient lighting consisting of multiple indirect lighting fixtures, each one serving a major lighting zone. These fixtures would be controlled by a continuous dimmer control with photosensitive sensors calibrated to maintain the ambient illumination levels in each zone at a fixed level of 30 footcandles.



2.5 WINDOWS

There are two primary types of windows with which this study is concerned: daylight windows and view windows. The daylight window is sized and positioned to admit daylight into the room. The view window also admits light into the space, but its primary purpose is to provide a view into the surrounding environment. These windows may be separately located so that different glazing, shading devices, etc. can be employed to best suit their specific criteria.

The daylight window lights the room for needed tasks. It should be sized and positioned to reduce or eliminate glare for patients and caregivers. It is important to consider the need to view flat touch-screens at the bedside, wall-mounted televisions, headwalls, and other medical equipment when designing the placement and shading of daylight windows.

The view window should be sized and placed to allow views from the patient's bed. This window should be shaded or of low V_T value for glare control, with control given to both patient and caregiver. This window, while admitting light into the room, functions primarily as the patient's view to the outside, thereby relieving stress, promoting relaxation, and even preventing delirium (Devlin & Arneill, p. 680).

Another type of fenestration in hospital patient rooms is interior glazing. Since current healthcare trends have eliminated inpatient care for lower acuity patients, most of today's admitted patients are in far greater need of observation (Kliment, p. 139). Architecturally, this can be accommodated by installing glazing at the inboard side of the room or by having glazed breakaway doors. In intensive care units, caregivers must be able to see all patient beds from the nurses' station. This is for the safety of the patient, as well as for nurse productivity. The use of interior glazing can have an effect on the daylighting of the room as glass has a relatively low reflectivity. This in turn can reduce the IRC and lower the overall value of the daylight factor. However, the effects of interior glazing were not incorporated into the modeling and testing here.



2.6 INTERIOR CONFIGURATION

Zoning

Every room has three designated occupancy zones: patient, family, and caregiver. The patient zone is the bed and the area immediately surrounding it – usually a zone of 3 feet around the

sides and foot of the bed. The caregiver zone is adjacent to the hallway and has immediate access to the patient zone. The family zone is also adjacent to the patient zone and is usually located on the outer wall.

Current trends are increasing the integration of family members as caregivers. Hospitals are focusing on “treating the person vs. treating the disease” (Kliment, p. 191). Locating the patient zone in proximity to the family zone and view windows can positively affect patient and family well-being. A desirable strategy is to place the caregiver zone in a location that is well supplemented by light from the daylighting window while strategically locating the patient zone so that it is not affected by glare. Also, the ability of patients to see a visitor’s facial expressions is a function of the amount of light on the visitor’s face, which is also a function of room zoning and window location. To this end, the rooms should ideally be zoned so that the family zone is not between the patient and the window. This keeps the faces of the family from being backlit, making them difficult for the patient to see, and ensures the patient an unobstructed view of the window.

Figure 20 gives an example of nine possible zoning strategies based on three zone relationships: the caregiver zone must be adjacent to the corridor, the patient zone must be adjacent to the caregiver, and the family zone must be adjacent to the patient zone. Most patient rooms are zoned as Type 1 in Figure 20, with the family zone on the outboard edge, the patient zone in the middle, and the caregiver zone on the inboard edge. There may be some flexibility in zone location based on the allowable width and depth of the room. For example, in a sufficiently wide room there may be more than one zone that has immediate access to the outboard edge, and consequently will have better daylighting qualities. Type 5 in Figure 20 is a good instance of this zoning possibility, which was used with several models in this study.

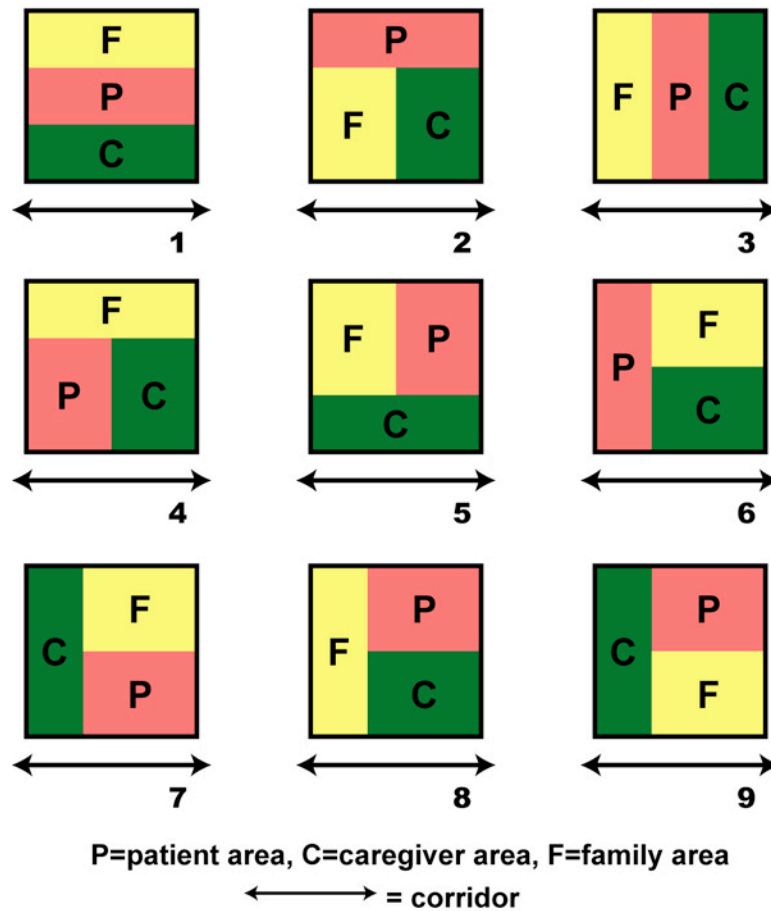


Figure 20 - Different combinations of room zones.

The following zone relationships are used: the caregiver area is adjacent to the corridor, the caregiver area is adjacent to the patient area, the family area is adjacent to the patient area. Most of the room models tested in this study fall into Type 1 or Type 5.

Reflectivity

The amount and distribution of the daylighting is largely dependent on the reflectivity in the room. The amount of daylight available in a given space depends on two primary components: the direct sky component (SC), which is the light received directly from the luminous sky, and the internally reflected component (IRC), which is determined by the size and position of the windows and the reflectivity values of the surfaces and objects in the space.

Since the IRC contributes a significant proportion of the total daylight factor, it is beneficial to employ strategies that maximize the IRC. Rooms with high IRC values do not need to have high daylight window heights to achieve the same level of illumination in the back of the room. Also, rooms with high IRC values have fewer problems with glare, as it reduces adaptation problems between the window and the rest of the field of view.

A high IRC is achieved by having high reflectivity values for the surfaces and furniture in the room. This allows the daylight to reflect off these surfaces and penetrate further into the room. Recommended reflectivity values are:

- Ceiling reflectivity – 90%
- Wall reflectivity – 70%
- Floor reflectivity – 40%
- Furniture/equipment reflectivity – 70%



2.7 ROOM GEOMETRY

Room Dimensions

From 1995 to 1997, a patient room flexibility study was jointly conducted by Zimmer Gunsul Frasca Partnership (Portland) and NBBJ (Seattle) for their client the National Institutes of Health (NIH). Using the strict NIH requirements for single bed patient rooms as a base case, the design team examined 12 recent hospital designs. They explored a variety of room widths ranging from 14' to 16'-6" and concluded that the best size for providing flexible design options is a 32' structural module. This module provides for two patient rooms (12'-9"w) with shared-wall toilets between them or wider rooms with toilet rooms inside each room. The target square footage equaled 250 sf.

For the purposes of this study, room widths of 12', 14' and 16' were considered to be representative of the range of designs that would conceivably be built. Similarly, room depths of 13', 16' and 19' were used in order to include the minimum suggested depth as well as realistically larger options. The resulting rough floor areas ranged from 182 to 304 square feet. See Appendix C for dimensions and details of the models that were tested.

Edge Condition

The edge condition, or configuration of the outer wall, has an effect on the daylighting of hospital patient rooms. The most common is one with a flat outer wall. However, a survey of recently constructed hospitals identified a number of other edge conditions that may be commonly considered for future hospital construction projects (Kliment, pp.140-150). Based on these observations, four other edge conditions were chosen for this investigation: corner window, notched, slanted and pointed. Figure 21 shows all edge conditions considered.

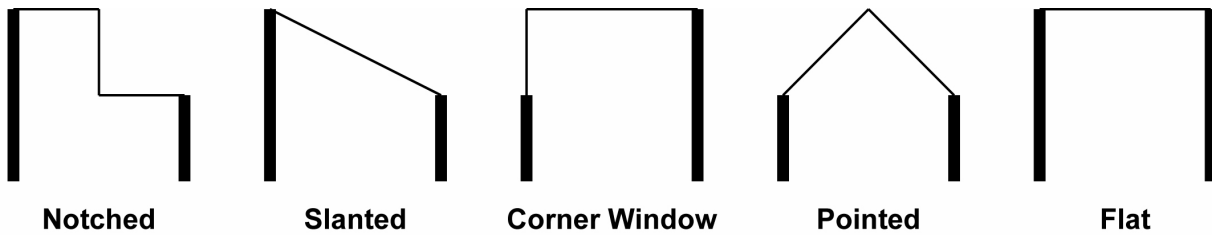


Figure 21 - Types of edge conditions considered in this study

Ceiling Height and Configuration

The configuration of the ceiling plane of the patient room influences daylighting. A higher ceiling allows for higher windows and deeper daylight penetration. This study analyzes two configurations: flat and angled. A flat ceiling consists of a planar ceiling of acoustical tile or gypsum board that hangs parallel to the floor plane. An angled ceiling slopes down from the bottom of the structure at the outboard wall to the nominal ceiling height at the inboard wall, allowing windows to sustain a higher head height. With some configurations of slanted ceilings and proper duct location, it may be possible to reduce floor-to-floor height while maintaining an adequately high daylight window head height. Figure 22 shows rooms with flat and slanted ceilings, along with structural and HVAC options.

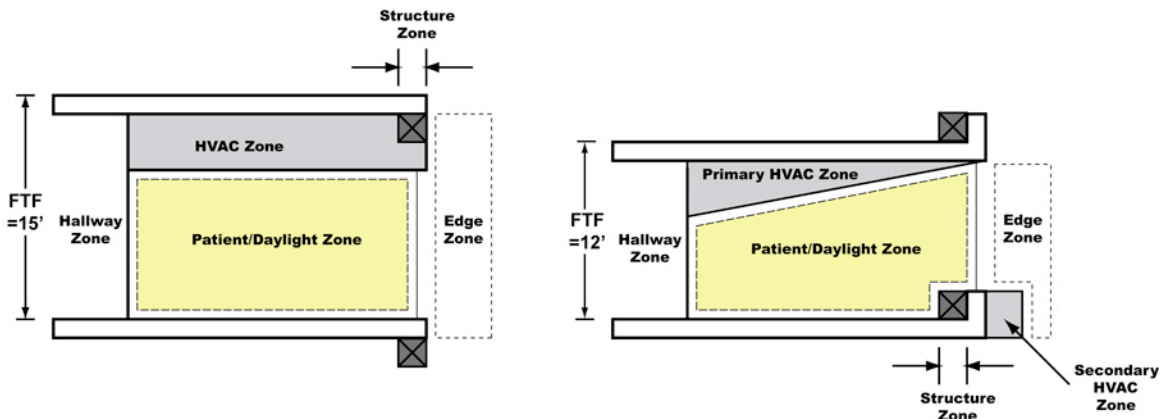


Figure 22 - Variation in ceiling planes, with options in HVAC and structural systems, resulting in varying floor-to-floor heights.

Toilet Location

An issue that bears upon both daylighting and patient well-being is the location and size of the patient toilet room. There are three general locations to be considered: inboard, outboard, and shared-wall. An inboard toilet is located adjacent to the interior corridor that connects the room with the rest of the unit, and opposite the exterior wall. An outboard toilet room is placed along the exterior wall. Shared-wall toilet rooms occur between two adjacent patient rooms. They are stacked behind one another, allowing for good visibility within the room. Figure 23 illustrates these variations.

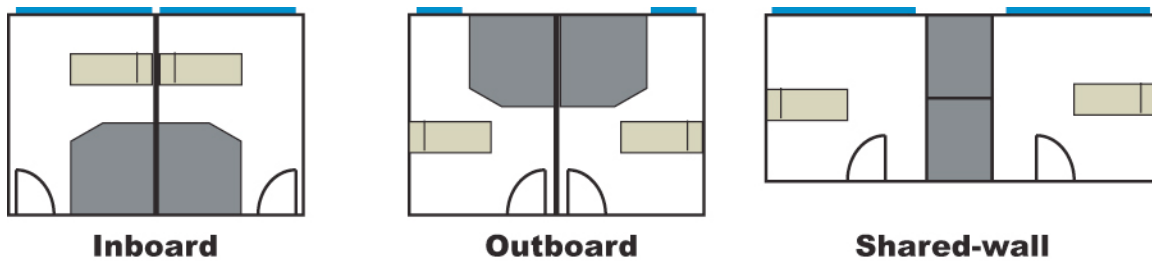


Figure 23 - Toilet locations

Toilet room sizes have been broken down into four subcategories: minimal size, integrated shower, shower stall, and tub room. Minimal size rooms contain a toilet and lavatory, but are not compliant with ADA guidelines. They are dimensionally a minimum of 3' x 5', and allowable as long as the code-minimum of ADA-compliant rooms is provided on the affected floors. Integrated shower rooms also have a toilet and lavatory, with a showerhead pointed directly into the tiled room. With minimum dimensions of 6'-3" by 6'-5", these toilet rooms allow ease in patient access and maintenance. A shower stall room may or may not be ADA compliant, but includes a toilet, lavatory, and separate shower stall. Its minimum dimensions are considered to be 8' by 8'-6". Lastly, a tub room measuring at least 6' x 9' contains a toilet, lavatory, and tub. As with the shower stall room, this type may or may not be ADA-compliant.



2.8 STRUCTURE AND HVAC

Structure

The building's structural components shape a room. The typical structure for a hospital tower is steel column and beam with two rooms per bay, a structure that requires a perimeter beam. However, it may be feasible to improve patient room daylighting and decrease building costs by utilizing an alternative structural system.

Options for reducing or eliminating the perimeter beam include using load bearing walls and hollow core pre-cast concrete planks. The use of load bearing walls supports the floor decking and spans from wall to wall. Bearing wall construction is perpendicular to external walls, permitting floor-to-ceiling glazing as well as providing thermal mass. However, it can be costly and time-expensive, and may eliminate future flexibility. Hollow-core pre-cast concrete planks show potential as a structural approach conducive to daylighting. These hollow planks are 10" – 12" thick and require a 2" topping slab. They can span from beam to beam for approximately 30'. The edge beam condition is replaced with an upturned steel angle. This 14" composite assembly is much thinner than a typical perimeter beam, which is usually 18" – 24". While this

mode of construction is not typically cost competitive, it can be quickly constructed and provides a larger perimeter opening.

Two strategies that hold the most promise are the use of a post-tensioned slab system and the use of an upturned perimeter beam. Using a post-tensioned slab also provides the opportunity for floor-to-ceiling glazing while eliminating the end-beam condition. This method is time intensive and creates a minor reduction in future flexibility in floor penetrations. However, there is evidence that filling the tendon cavity with grout can mitigate this limited flexibility in floor penetrations.

Upturning the perimeter beam is an option when constructing in either steel or concrete. Both systems may allow for smaller floor-to-floor heights and, with the use of sloped ceilings, larger daylight glazing, thus reducing construction costs and improving patient room daylighting. Figure 24 shows these two systems along with HVAC location options that may result in improved performance.

Note that there may be some code restrictions governing construction systems and dimensions. This is particularly true for operating room areas, which typically have stringent restrictions on allowable vibration transmittance. Overall, however, with shorter floor-to-floor distances, money can be saved on construction materials and invested instead on more effective daylighting techniques.

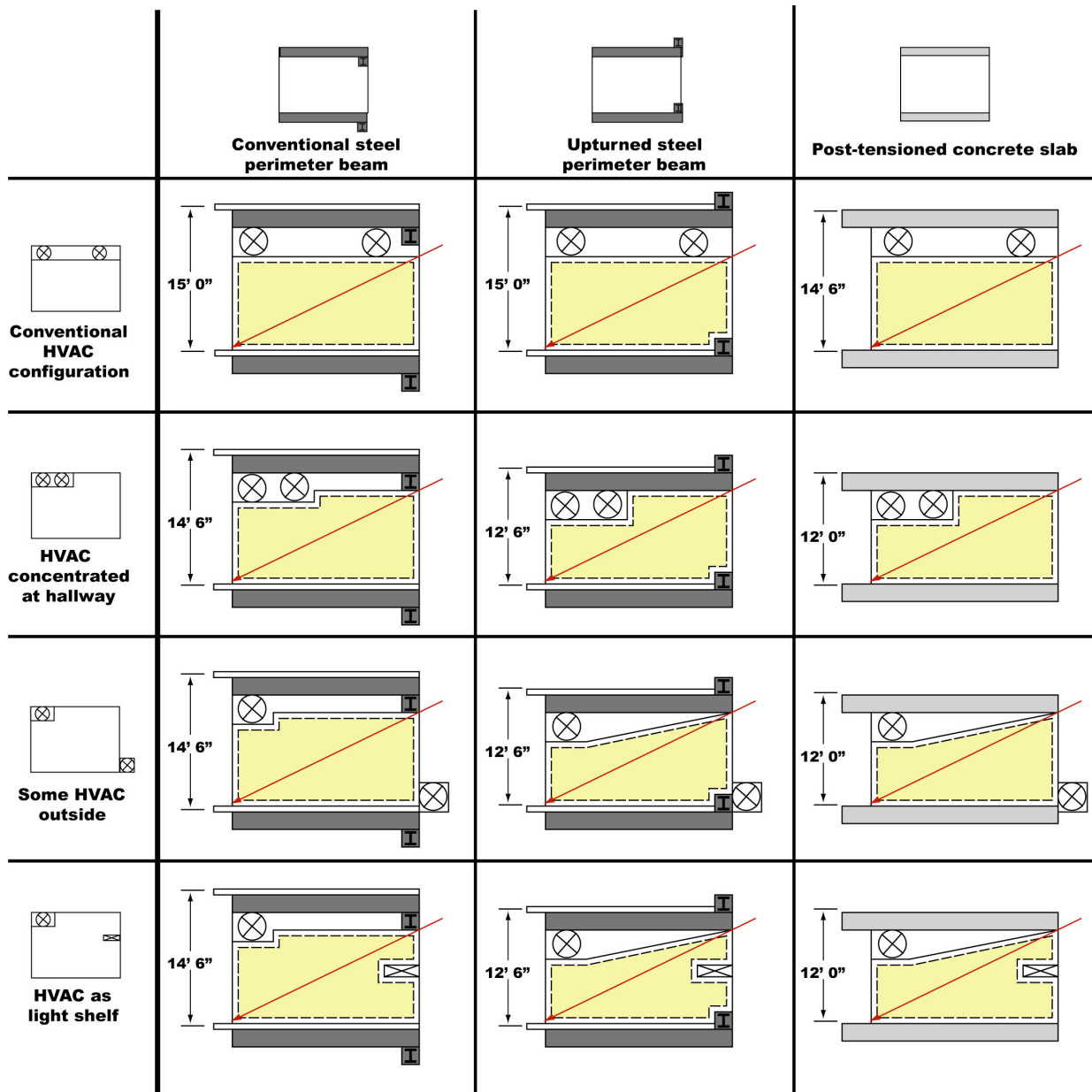


Figure 24 - Matrix showing possible combinations of structural types and HVAC locations.
The red lines indicate window head height and sun cutoff angle to achieve a given d.f. at the back of the room. The length and angle of the lines are identical.

HVAC & Mechanical Systems

Typical hospital HVAC systems have three large ducts for the ventilation of patient rooms: supply, return, and exhaust. These ducts are arranged so that they do not cross on top of one another, which would necessitate a larger plenum. Engineers reportedly prefer working with a 42" – 48" plenum. In the past, the supply duct was placed along the perimeter of the building to offset drafts from inefficient glazing. Now that the technology and quality of glazing has

improved, the supply, terminal unit (serving 3-4 rooms), and reheat coils are usually accessed on the inboard side through the corridor. The perimeter HVAC duct is typically used as a return duct. In addition, a radiant fin tube is used at the base of the perimeter window. This duct and its supply register can be as far as 10' away from the exterior window. The use of a two-duct system with 100% heat reclamation may be more efficient than a three-duct system.

Engineers must comply with specific mechanical design guidelines for hospital patient rooms, including those devised by the ASHRAE, JCAHO, NIH, CDC and Infection Control. Airflows may be negative, positive, or neutral, depending on patient acuity, type of sickness, and room occupancy. For the purposes of this study, only single occupancy rooms are examined. In general, the systems are designed for 6 air changes per hour per patient room with a neutral flow. The goal is to prevent airflow from patient room to patient room and to provide a comfortable patient environment. This means that mechanical engineers must take into consideration thermal comfort, drafts, and acoustics when placing and sizing air-handling vents and equipment. For instance, a 24" w x 10" h return duct might be placed within a light shelf at the outboard side of the room to allow for a higher ceiling height and glazing. However, problems with this example include difficulties at the end of the duct runs with routing it back to the ceiling plenum, as well as unwanted thermal gains and losses due to the duct's proximity to the outside environment.

3.0 ANALYSIS AND PHYSICAL MODEL TESTING

An initial matrix of room geometries was developed that outlined a broad array of combinations of room dimensions and toilet sizes, from which a list of possible combinations was selected for numerical analysis. Figure 25 and Figure 26 show a preliminary matrix of room and toilet sizes. Eighteen room configurations were developed and analyzed numerically. Based on the results of this analysis, design configurations were identified as being of potential interest and were subsequently tested using physical models in a mirror-box artificial sky.

Inboard				Outboard				Shared Wall				Square	Minimum Width (12')
Shower Stall (68 sf)	Tub Room (54 sf)	Integrated Shower (42 sf)	Minimal Size (15 sf)	Shower Stall (68 sf)	Tub Room (54 sf)	Integrated Shower (42 sf)	Minimal Size (15 sf)	Shower Stall (68 sf)	Tub Room (54 sf)	Integrated Shower (42 sf)	Minimal Size (15 sf)		
												Small (160 sf)	
												Med. (200 sf)	
												Large (245 sf)	
												Mega (290 sf)	
Entry sizes do not meet 5' minimum												Small (160 sf)	Minimum Width (12')
												Med. (200 sf)	
												Large (245 sf)	
												Mega (290 sf)	

Figure 25 - Preliminary room size/toilet matrix for square and minimum width rooms. Highlighted configurations are similar to those that were physically modeled.

Inboard				Outboard				Shared Wall							
Shower Stall (68 sf)	Tub Room (54 sf)	Integrated Shower (42 sf)	Minimal Size (15 sf)	Shower Stall (68 sf)	Tub Room (54 sf)	Integrated Shower (42 sf)	Minimal Size (15 sf)	Shower Stall (68 sf)	Tub Room (54 sf)	Integrated Shower (42 sf)	Minimal Size (15 sf)				
												Minimum Depth (13')			
			Does not meet minimum dimension requirements				Does not meet minimum dimension requirements				Does not meet minimum dimension requirements	Maximum Bay Size (bay=32'6")			

Figure 26 - Preliminary room size/toilet matrix for minimum depth and maximum width rooms. Highlighted configurations are similar to those that were physically modeled.

3.1 ANALYTICAL SKY COMPONENT CALCULATIONS

The sky component (SC) at the back of the room for a variety of room configurations was calculated based on the BRS Protractor method. These calculations estimated the direct sky component of the daylight factor, or the amount of the overcast sky “seen” at the back of the room. Other factors such as the internally reflected component were not considered. A series of traces representing different combinations of ceiling configurations, floor-to-floor heights, and room depths were plotted over a number of x-axis values, which represented combinations of toilet sizes, toilet locations, and room widths, as shown in Figure 27.

For the purposes of this study, the daylight window was of primary importance. The geometry of the daylight window was specified by a sill height of either six or eight feet. Other morphological factors such as ceiling height and room width also determined the total size of the daylight window in the calculations and models, as the window was considered to extend the width of the room and from the specified sill height to the ceiling.

The best overall sky component performance, as indicated by the heavy solid blue line, was obtained by a 13’ deep room with an angled ceiling and a 15’ floor-to-floor height. The worst overall performance, as indicated by the light dashed red line, was obtained by a 19’ deep room with a flat ceiling and a 13’ floor-to-floor height. All of the other combinations of room depths, floor-to-floor heights, and ceiling configurations fell somewhere between these two extremes.

Rooms with minimal size toilet rooms had good overall performance, as the small toilet room profile did not obstruct the admission of daylight into the rooms. The most pronounced peak in the traces occurs with a minimal size toilet room at an inboard location in a 16’ wide room. Noticeably poorer performance occurs in rooms with outboard toilets, as would be expected. The lowest point for the traces occurs in a 12’ wide room with a shower stall toilet in an outboard location.

These results confirmed the initial hypothesis that the best sky component performance would result from rooms that were shallow and wide with high ceilings, which would allow for large daylight windows. As anticipated, rooms with outboard toilet locations performed poorly in comparison with those with inboard or shared-wall toilets. Rooms with smaller toilets, such as the minimal size configuration, had better performance as there was less light obstructed by the toilet room.

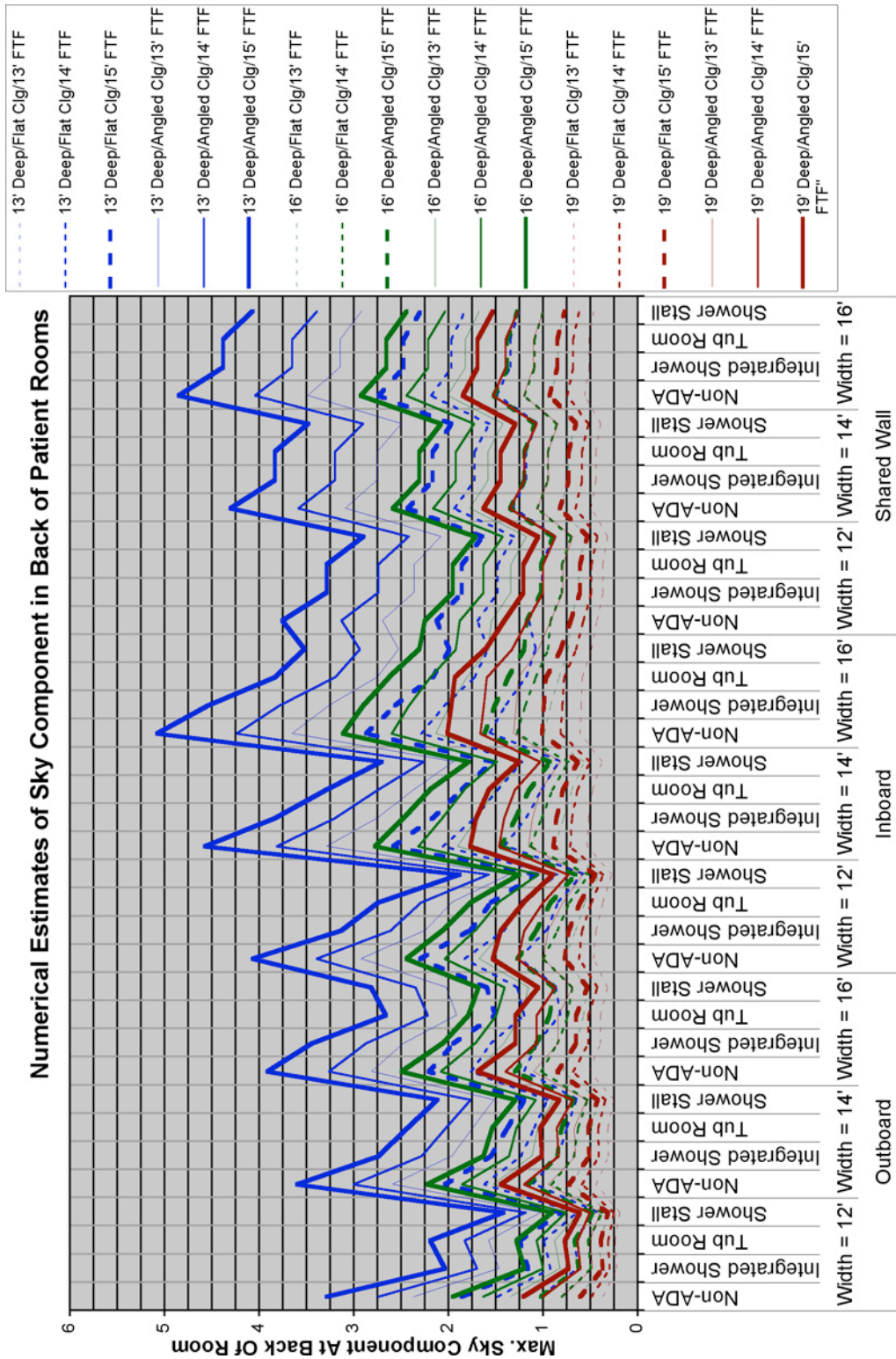


Figure 27 - Results of initial numerical analysis

The same numerical estimation technique was performed for each of the edge conditions, with values derived for full- and half-length windows. Figure 28 shows the results of these calculations. Note that the results have been normalized, with the largest value calculated assigned a value of 100%, and all other values interpreted as a proportion of that maximum value. This was done because the purpose of these initial calculations was primarily to compare physical characteristics.

For each edge condition, calculations were performed for windows that stretched the full width of the room and for windows that stretched from one edge to the middle of the outer wall. The purpose of this comparison was to investigate the possibility of obtaining adequate daylight with smaller glazing areas. As the traces in Figure 28 indicate, some half-length windows on certain edge types performed as well or better than full-length windows on other edge types. However, difference in performance between half-length and full-length daylight windows was determined to be of minor significance and was subsequently abandoned in the next phase.

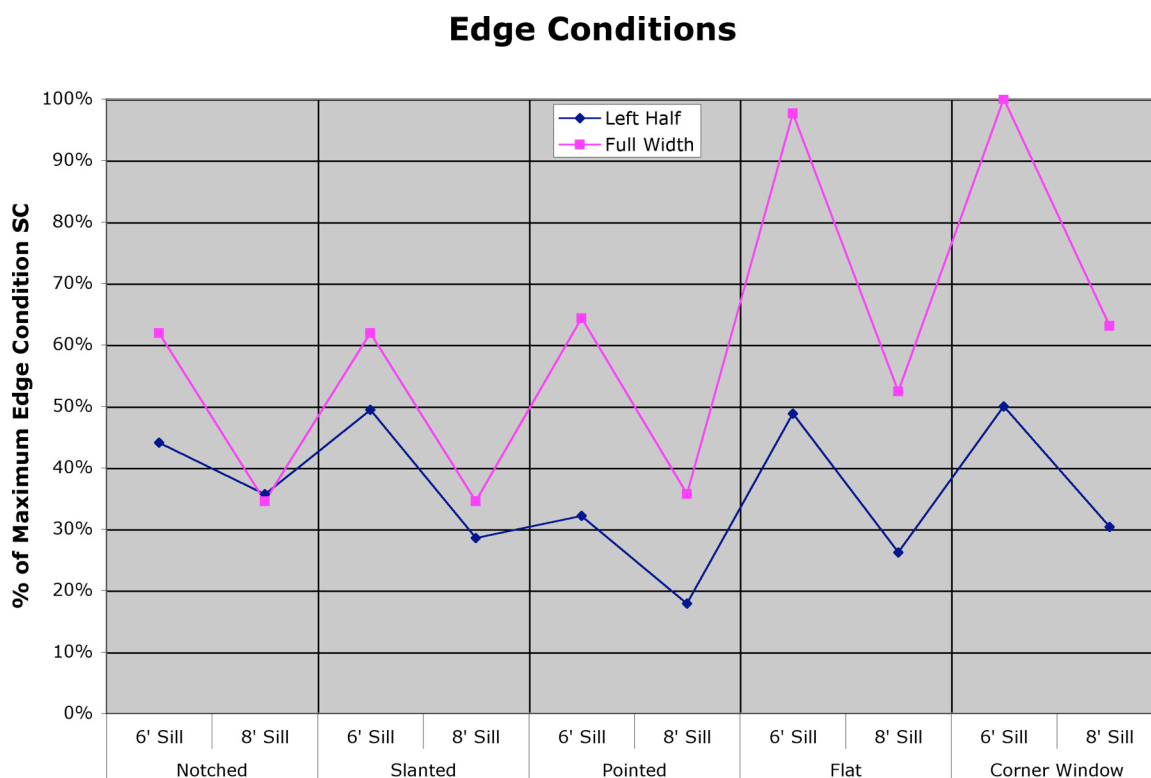


Figure 28 - Effect of edge conditions on sky component

Of the 18 edge conditions examined, the best performance was obtained from flat and corner window designs. The notched, slanted, and pointed conditions (see Figure 21) all showed a consistent performance, at about 60% of that obtained from the other two edge conditions. The results of this analysis also indicate that a 6' sill height results in higher daylighting levels than an 8' sill height. This is to be expected since the lower sill height allows for larger daylighting

windows. The half-length windows performed at approximately 50% of the level of the full-length equivalents.

3.2 TEST MATRIX

From the results of the initial numerical analyses, a preliminary test matrix was derived. The characteristics included in the matrix were chosen to represent a cross-section of possible configurations. In some cases, these configurations included characteristics that were known to result in poor daylight performance (e.g. outboard toilet rooms). These were included so we could ascertain the magnitude of the effects of these poor performance characteristics in order to develop solutions for these performance shortcomings. This matrix was revised before the actual testing began based on practical design limitations; for example, those designs with 8' sill heights and 8.5' ceiling heights were revised to have either higher ceilings or lower sill heights. Figure 29 gives the basic characteristics of the 29 configurations tested. A more detailed matrix can be found in Appendix B.

Model #	Toilet Type	Toilet Location	Room Width	Room Depth	Ceiling Height	Ceiling Type	Edge Type
1	Shower stall	Outboard	14'	19'	9.25'	Flat	Flat
2	Shower stall	Inboard	14'	19'	9.25'	Flat	Flat
3	Shower stall	Shared-wall	14'	19'	9.25'	Flat	Flat
4	Shower stall	Outboard*	14'	19'	10'	Flat	Flat
5	Shower stall	Outboard**	14'	19'	10'	Flat	Flat
6	Shower stall*	Inboard	12'	19'	8.5'	Flat	Flat
7	Integrated shower	Outboard	12'	16'	9.25'	Flat	Flat
8	Shower stall*	Outboard**	16'	13'	9.25'	Flat	Corner
9	Integrated shower	Outboard*	16'	19'	9.25'	Flat	Corner
10	Tub room	Shared-wall	16'	16'	8.5'	Flat	Notched
11	Shower stall	Inboard	14'	19'	9.25'	Flat	Slanted
12	Shower stall*	Inboard	14'	19'	9.25'	Flat	Pointed
13	Integrated shower	Shared-wall	14'	13'	9.25'	Flat	Pointed
14	Shower stall	Shared-wall	14'	19'	7.75'	Slanted	Flat
15	Shower stall	Inboard	14'	19'	7.75'	Slanted	Flat
16	Integrated shower	Shared-wall	16'	16'	10'	Slanted	Flat
17	Minimal size*	Inboard	16'	13'	10'	Slanted	Flat
18	Tub room	Shared-wall	12'	19'	10'	Slanted	Flat
19	Tub room*	Inboard	14'	16'	8.5'	Slanted	Pointed
20	Tub room	Shared-wall	12'	16'	10'	Slanted	Notched
21	Shower stall	Shared-wall	14'	16'	8.5'	Slanted	Slanted
22	Shower stall	Inboard	14'	16'	8.5'	Slanted	Slanted
23	Integrated shower	Shared-wall	12'	19'	9.25'	Flat	Flat
24	Integrated shower	Shared-wall	12'	14'	8.5'	Flat	Notched
25	Integrated shower	Shared-wall	12'	16'	9.25'	Flat	Pointed
26	Integrated shower	Shared-wall	12'	19'	7.75'	Slanted	Flat
27	Integrated shower	Shared-wall	12'	16'	10'	Slanted	Flat
28	Integrated shower	Shared-wall	12'	16'	8.5'	Slanted	Slanted
29	Integrated shower	Inboard	14'	16'	8.5'	Slanted	Pointed

Figure 29 - Table of major design characteristics of test models

Entries with an asterisk (*) indicate toilet rooms that will not fit with design guidelines

3.3 TEST ASSUMPTIONS AND GENERAL PROCEDURES

For each of the configurations under consideration, a model was constructed and tested in the ESBL mirror-box artificial sky at the University of Oregon. The artificial sky is a device that simulates the daylighting conditions of the CIE Standard Overcast Sky. This assumes a distribution of light that is three times brighter at the zenith than at the horizon and evenly distributed around the horizontal plane (i.e. does not vary by compass orientation).

Each model was built to a scale of 1" = 1' and tested with nine sensors arrayed on the floor of the model to record the illumination level at that particular spot in the room. The sensors were placed to record the illumination levels at 30" (to scale) above the floor of the room. These illumination levels were automatically compared with those of a sensor external to the room model to return values for the daylight factor for the nine sensors in the room model. See Appendix C for diagrams of the relative sensor positions for each test.

The issue of furniture in the rooms and its potential effect on the daylight factor distribution was considered. An initial test was performed on a room with scale model furniture located in typical positions in the room. The test was then repeated without the furniture models. The average daylight factor of the model with furniture was 4.9; the same room without furniture was 4.6. This difference was considered to be insignificant, and it was decided to proceed with the remainder of the tests without furniture in the models. Figure 30 shows a diagram of the room layout for the furniture test. The circled numbers indicate sensors.

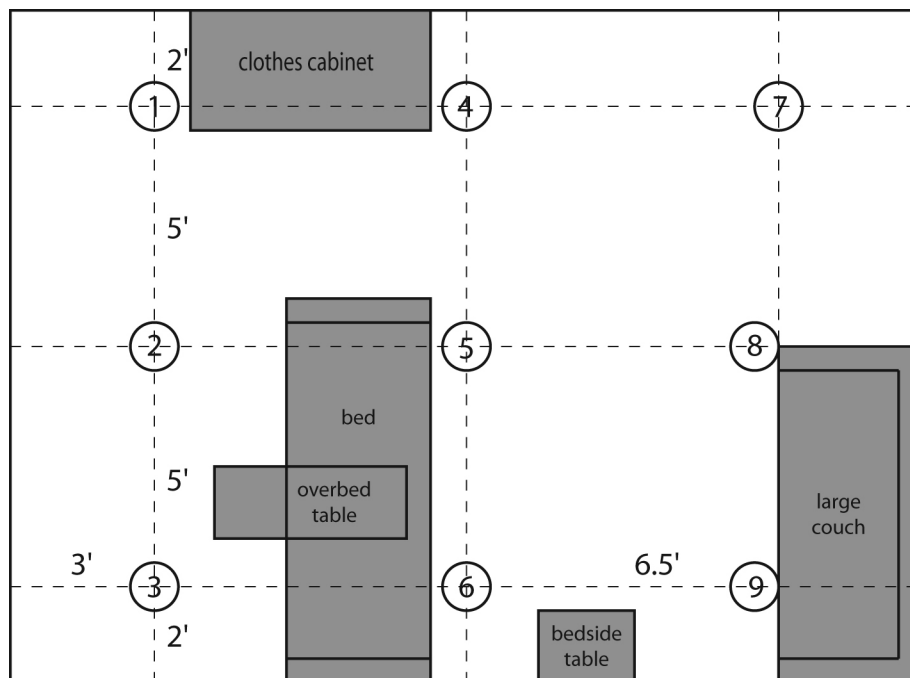


Figure 30 - Test performed with furniture in the model.

3.4 OVERVIEW OF TEST MODELS

There are a number of assumptions and parameters common to all of the models and tests. These were implemented to help simplify the large number of combinations of design factors. The following sections outline some of the assumptions and methods common to all of the models.

Structure and Room Height

The structure of the rooms was assumed to be steel frame construction. The depth of the structural elements was assumed to be 2'6" in all cases. The assumed plenum depth was calculated by the following equation:

$$\text{plenum depth} = \text{floor-to-floor height} - \text{ceiling height} - 2.5 \text{ feet}$$

Figure 31 shows the array of floor-to-floor heights, ceiling heights, and plenum depths used for the models.

Floor-to-floor Height	Ceiling Height	Plenum Depth
15'	10'0"	2'6"
14'	9'3"	2'3"
13'	8'6"	2'0"
12'	7'9"	1'9"

Figure 31 - Heights on models tested

The plenum depths were designed to be able to accommodate several types of ducts: a 12" by 12" supply duct, a 20" by 28" return duct, and possibly a 12" by 12" exhaust duct. In some cases it was assumed that the exhaust duct could be located outside of the plenum.

Two types of ceiling configurations were tested: flat ceilings and slanted ceilings. The first 13 tests were conducted on models with standard flat ceilings. The next 9 tests had ceilings that slanted up from the standard ceiling height to the height of the structure at the outside wall. (The remaining 7 tests were revisions of the first 22.) For details on the room layouts as well as the daylighting contour results, see Appendix C.

Toilet Rooms

Four types of toilet rooms were considered: a shower stall room measuring 8' by 8'6", an integrated shower room measuring 6'3" by 6'9", a tub room measuring 6' by 9', and a minimal size room measuring 3' by 5'. In all tests, the toilet rooms were oriented with their long axis in the direction of the length of the room, i.e. from inner to outer wall. Three positions were considered for the location of the toilet rooms: inboard, outboard, or shared-wall. The outboard toilets were located on the outer wall of the room (in the upper right-hand, or "northeast," corner in the diagrams in Appendix C). The inboard toilets were located on the inner wall of the room (in the upper left-hand, or "northwest," corner in the diagrams in Appendix C). Figure 32 shows an example room layout with an inboard tub room toilet. Rooms having shared-wall toilets were tested with no toilet room in them. Note that the gross dimensions of the room were not adjusted for toilet size or location. For example, a 14' by 19' room with a 6' by 9' inboard or outboard

toilet room would have a free area of 212 square feet (266 s.f. gross less 54 s.f. for the toilet), whereas a 14' by 19' room with a shared-wall toilet would have a free area equal to the gross square footage of 266 s.f.

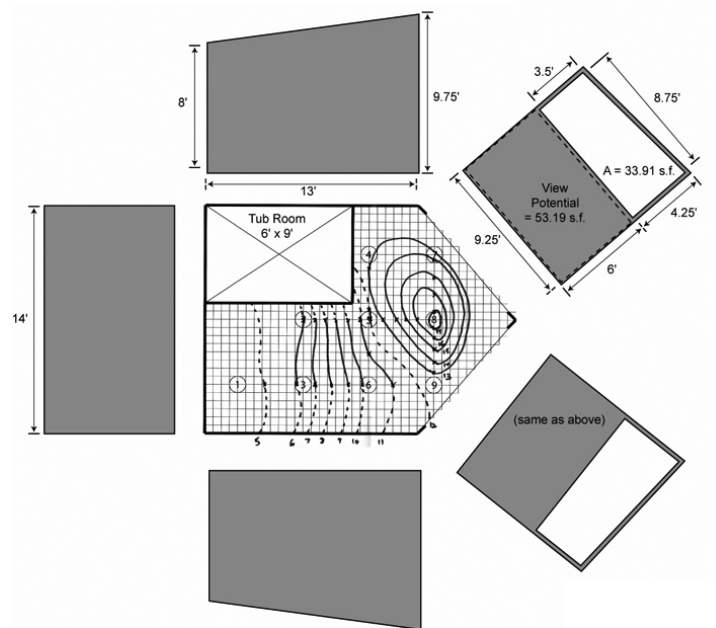


Figure 32 - Example test room layout (Model 19)

Edge Condition

The models were tested with the various edge conditions discussed in Section 2.7. For those models with edge conditions other than the flat outer wall, certain limitations were imposed. The edge condition was designed to be six feet past the orthogonal part of the room. For example, for a pointed edge condition, the angled walls forming the point extend six feet from the parallel side walls. Figure 32 shows an example room layout with a pointed edge condition. With the angled edge condition, the apex of the angle is six feet from the parallel side walls. Similarly, for the notched edge condition, the notched area only extends six feet beyond the main portion of the room. For the corner window edge condition, the window extends six feet around the corner from the outer wall. For rooms with the pointed, notched or angled edge conditions, the room geometries were adjusted so that they would have the same gross area as a rectangular room of the same nominal width and depth. For precise dimensions for the models, see Appendix C.

Window Size & Sill Height

The windows tested in the models were for the most part daylight windows only. The sill heights were either 6' or 8', with the head height dependent on the ceiling height and whether the ceiling was slanted. The lengths of the daylight windows were maximized by stretching them from wall to wall. For rooms with inboard and shared-wall toilet locations, the daylight window stretched the entire length of the room, less 3" on either side for mounting hardware. For rooms with outboard toilets the window stretched from the room wall to the outer wall of the toilet room, once again allowing 3" on either side for mounting hardware. The wall area below the daylight window was considered to be "view opportunity," allowing the designer to place a view window

as may best suit the situation. The area of this “view opportunity” may be used as one gauge for patient well-being, as discussed in Section 2.3. The area for the view opportunity was the width of the wall below the daylight window multiplied by the height of the daylight window sill, less 3” for hardware. Figure 32 shows a room layout with 6’ high sills.

Windows also were designed for the outboard toilet rooms, sized to provide a daylight factor of 2% for the toilet room area. However, as the testing was primarily concerned with the daylighting of the main patient area, there were no sensors in the toilet room areas for most of the tests, and in these cases the bathroom windows were blocked during testing. The exception to this was in cases where the toilet rooms had translucent or shortened walls. In order to overcome the daylight deficit inherent in outboard toilet room location, it was decided to implement two strategies that would allow better daylight in the back of the room: toilet rooms with translucent walls and shortened toilet rooms. The translucent toilet wall configurations (Models 5 & 8) were assumed to have toilet room walls of textured glass that would allow light from a window located inside the toilet room to pass through the outboard toilet room while maintaining patient privacy. The toilet room would be configured so that all of the plumbing and services could be placed along the interior toilet room wall, allowing for the full height of the toilet room walls to be unobstructed. The shortened toilet room configurations (Models 4 & 9) had a flat ceiling of 10 feet in height. This higher ceiling height was to allow the top of the shortened toilet room to act as a light shelf for an additional window placed above the toilet room. The toilet was an outboard shower stall room that was 7’ high, allowing for 3’ of space to reflect light into the back of the room. See Appendix C for more details about these configurations.

4.0 TEST RESULTS

The following sections describe the results of the testing. In the first section, we rank the models using three main criteria; in the second section, we make some observations about the effect of specific morphological variations on the daylighting performance of the models.

4.1 MODEL RANKINGS

The models were assessed and ranked according to four criteria: the perceived quality of daylight, quantitative measures of light intensity, view potential, and electric savings.

Perceived Quality of Daylight

This was a largely subjective ranking. Overall, the desire was to have an adequate amount of daylight in the room, with an even distribution throughout. More specifically, three criteria were used as a guideline for ranking daylight:

- *Target daylight factor* – The goal was to have a daylight factor (d.f.) of 2 at the back of the room. Most of the models met or exceeded this criterion. Models below but with values close to the target were ranked higher than those exceeding it. Models with illumination levels significantly greater than the target daylight factor, generally those with a daylight factor of 10 or more, were ranked relatively low.

- *Bright spots* – Small spots of intense daylight were considered to be unfavorable, and models with bright spots were ranked relatively low.
- *Gradient* – A shallow gradient of daylight factors was considered to be less conducive to glare and so was looked upon favorably. Models that had gradients greater than approximately 6 daylight factors across the room were ranked relatively low.

Light Intensity

Models were ranked based on the average value of the daylight readings across the nine sensors in the model. The values ranged from a d.f. of 11.33 for Model 18 to a d.f. of 0.29 for Model 1.

View Potential

Models were ranked based on the square footage of wall space available for view windows, with the idea that a larger view window area would result in greater flexibility for view window placement and consequently greater patient well-being. The available area ranged from 143.4 s.f. for Model 12 to 34.5 s.f. for Model 5. Figure 33 shows the rankings for the models based on the criteria discussed above.

Electric Savings

Models were ranked based on the percentage of electric savings from lighting compared to a room that had no daylighting. Caution should be exercised in evaluating this ranking category in that only the lighting electric savings was considered. See Section 4.4 for more information on these calculations. Values for this category ranged from a 9% savings for Model 1 to an 87% savings for Models 13, 17, 18, 19 and 29.

Model #	Daylight Rank	Light Intensity Rank	View Potential Rank	Electric Savings Rank
1	29 th	29 th	26 th	29 th
2	18 th	9 th	18 th	7 th (3-way tie)
3	10 th	18 th	19 th	18 th
4	26 th	26 th	28 th	26 th
5	27 th	27 th	29 th	27 th
6	25 th	19 th	22 nd	19 th
7	28 th	28 th	27 th	28 th
8	4 th	25 th	8 th	25 th
9	17 th	12 th	16 th	10 th (4-way tie)
10	16 th	10 th	3 rd	10 th (4-way tie)
11	19 th	7 th	17 th	7 th (3-way tie)
12	3 rd	24 th	1 st	24 th
13	22 nd	3 rd	9 th	1 st (5-way tie)
14	12 th	15 th	20 th	15 th (2-way tie)
15	15 th	11 th	21 st	10 th (4-way tie)
16	8 th	6 th	4 th	6 th
17	7 th	5 th	5 th	1 st (5-way tie)

18	24 th	1 st	23 rd	1 st (5-way tie)
19	20 th	2 nd	10 th	1 st (5-way tie)
20	14 th	14 th	2 nd	14 th
21	2 nd	23 rd	6 th	23 rd
22	5 th	20 th	7 th	20 th (2-way tie)
23	13 th	16 th	24 th	15 th (2-way tie)
24	6 th	21 st	13 th	20 th (2-way tie)
25	21 st	13 th	14 th	10 th (4-way tie)
26	11 th	17 th	25 th	17 th
27	9 th	8 th	15 th	7 th (3-way tie)
28	1 st	22 nd	21 st	22 nd
29	23 rd	4 th	11 th	1 st (5-way tie)

Figure 33 - Test results rankings

4.2 OBSERVATIONS

Based on the results of the testing, it is possible to make some generalizations about how certain morphological factors affected the daylight performance of the models. The following sections discuss these observations.

Toilet Size and Location

The toilet size and location had an obvious effect on the results of the daylight testing. Models with outboard toilets had the worst performance in terms of overall daylighting, average intensity and view potential. Attempts to ameliorate these negative effects through the use of translucent toilet walls or shortened toilet walls with reflective ceilings showed some promise – in particular, using a translucent toilet wall with a corner edge condition (Model #8), which resulted in the best daylighting performance with outboard toilet rooms. Overall, however, outboard toilet configurations were poor performers.

Inboard toilet configurations performed well, in most cases not affecting the daylighting performance of the model. However, in cases where the toilet is relatively large in relation to the overall floor size, reflections from the toilet wall may result in an uneven distribution of light across the room. This is particularly noticeable for rooms with asymmetric edge configurations.

Overall, the best performers were those models with shared-wall toilets. This configuration, in effect, removes the toilet from the patient room entirely in terms of daylighting analysis. The daylight distribution is more even across the width and depth of the room, with no obstructions to the incoming light or irregular reflections in the back of the room from the toilet room walls. As far as daylighting purposes are concerned, the shared-wall toilet is clearly the desired configuration.

Figure 34 shows the performance of the models by toilet location. The y-axis represents the “daylight rank performance value,” which is the daylight rank number (first column in Figure 33) subtracted from 30. This metric was used in order to provide a higher value for better-performing models. As the chart indicates, the models with outboard toilets had noticeably poorer performance than those with inboard or shared-wall toilets.

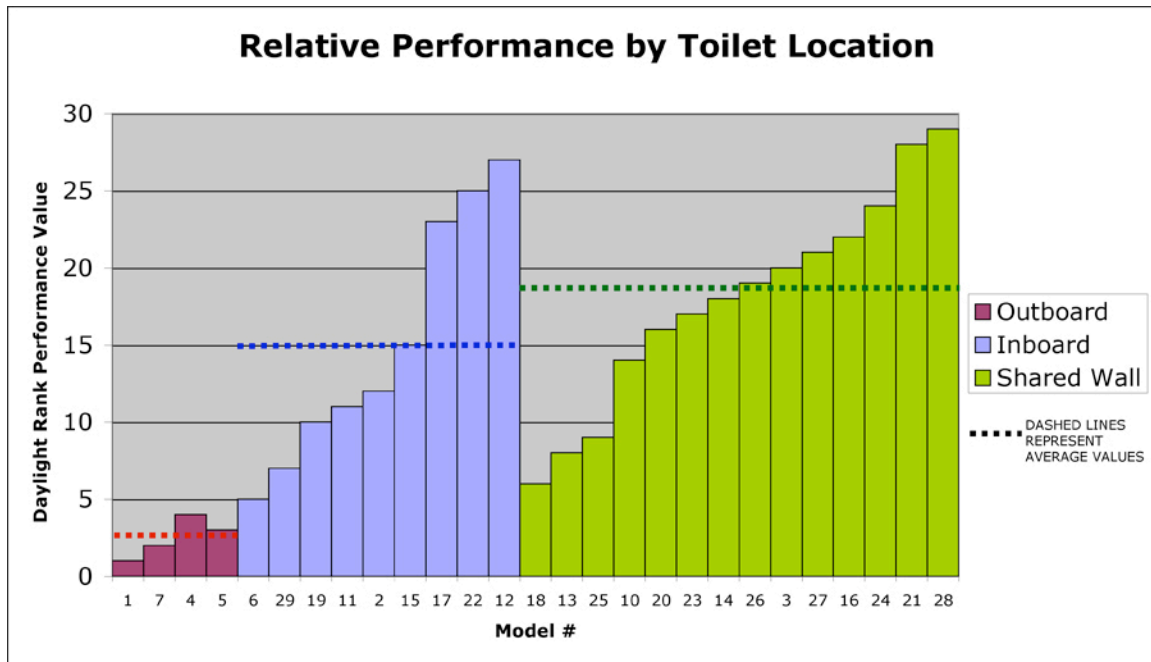


Figure 34 - Model performance by toilet location. "Rank performance value" is 30 minus the daylight rank number. Note that outboard toilet rooms with translucent walls are *not* included in this graph.

Sill Height

Another significant factor affecting the daylighting performance is the sill height of the daylight window. Predictably, the models with low sills had large glazing areas and consequently much higher light intensity in the room. Lower sills also resulted in better light penetration for narrow, deep rooms. However, the high levels of light afforded by the lower sills can also have a negative effect – many of the rooms with such windows had very large lighting gradients and some very intense bright spots. In fact, in the general ranking of performance, most of the models with low sills and large daylight glazing areas were ranked low because of these characteristics.

Consequently, rooms with higher sills actually performed better, provided there was enough room width available to allow a moderately sized daylight window (i.e. no outboard toilet). In fact, the top five overall daylight rankings went to rooms with an 8' sill and inboard or shared-wall toilets. Given adequate glazing area, the high-silled models generally had a more even distribution of daylight at levels closer to the target values, with fewer bright spots and a smaller gradient.

Figure 35 shows the performance of the models by sill height. The y-axis represents the “rank performance value,” which is the daylight rank number (first column in Figure 33) subtracted from 30. This metric was used in order to provide a higher value for better-performing models. As the chart indicates, the models with 8’ sills had better performance than those with 6’ sills.

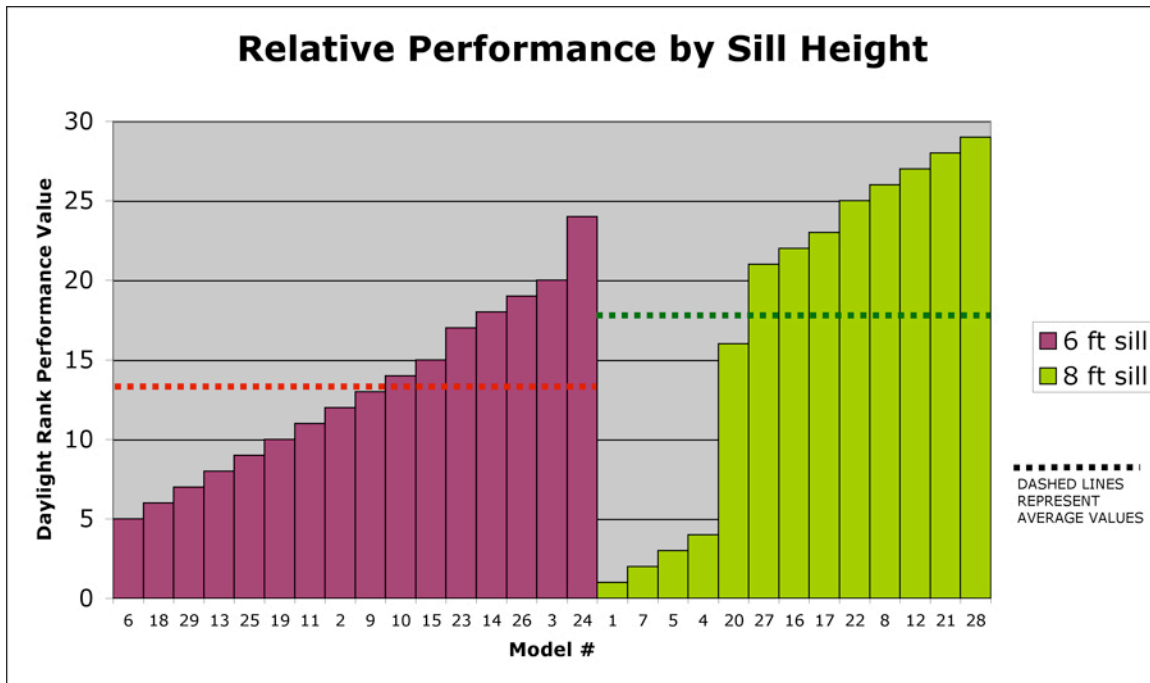


Figure 35 - Model performance by sill height. "Daylight rank performance value" is 30 minus the daylight rank number. The relatively low performance of Models 1, 7, 5 and 4 is due to their outboard toilet locations.

Figure 36 shows average values for daylight intensity (average value across the floor), the average daylight factor at the back of the room, and the gradient (the highest measured d.f. minus the lowest) by sill height. The models with the 6’ sill typically had higher values for all three of these metrics, which contributed to the relatively lower rankings for the 6’ sills (see Figure 35). This is because the daylight factor value of the 6’ sill models tended to exceed the target values used in the ranking process (see Section 4.1). The noticeably larger gradient values for those models with 6’ sills also indicated potential glare problems due to the high contrast of illumination levels between one part of the viewer’s field of vision and another.

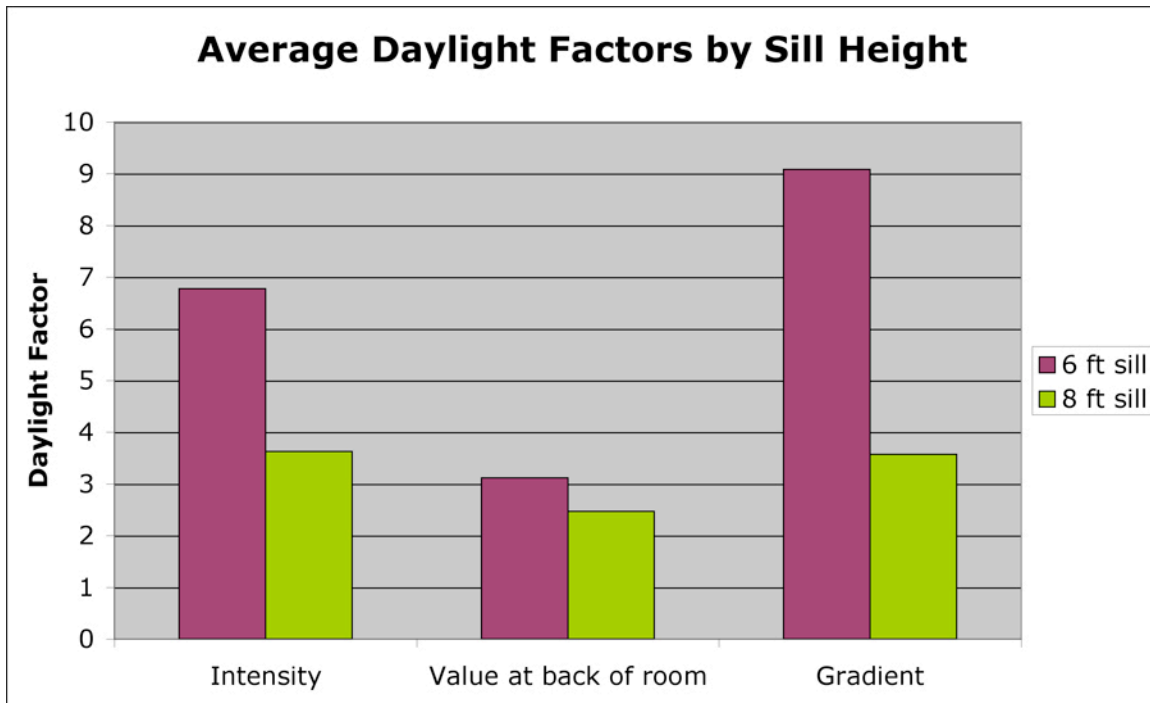


Figure 36 - Average model daylight factor values by sill height

Edge Conditions

Models with flat outer walls had fairly good daylighting performance, with a relatively even distribution of light across the width of the room for those configurations with inboard or shared-wall toilets. These configurations provided a good baseline of performance for comparisons with other edge conditions.

Rooms with pointed edges tended to have bright spots with high daylight factors that generally occurred at the middle of the base of the triangular edge. When combined with large glazing areas, this configuration resulted in bright spots with very large daylight factors and very steep gradients, and therefore potential glare problems.

Rooms with notched and corner edges tended to have a fairly good distribution of light across the room. The availability of two directions of light causes lower light level gradients and thus less glare in the room. These models also had higher view potentials. However, the increased size of the daylighting glazing also has the potential for introducing too much daylight into the room, particularly with low-silled daylight windows. Care should be taken to avoid having too much daylight glazing with these edge configurations in order to avoid unacceptably high illumination levels and glare.

Rooms with slanted edges performed very well overall. This edge condition also results in higher view potential given the longer outer wall. However, with flat-ceiling rooms the slanted outer edges can result in uneven distribution of light across the width of the room. This problem can be

addressed by using a slanted ceiling; this results in a larger daylight opening at the far edge of the room, thus mitigating the problem of uneven light distribution in the back of the room. Overall, the models with slanted ceilings and slanted edge conditions ranked very high in daylighting performance.

Figure 37 shows the performance of the models by edge condition. The y-axis represents the “daylight rank performance value,” which is the daylight rank number subtracted from 30. This metric was used in order to provide a higher value for better-performing models. As the chart indicates, the models with slanted edge conditions tended to have the best performance, while those with flat and pointed edges tended to have the lowest performance.

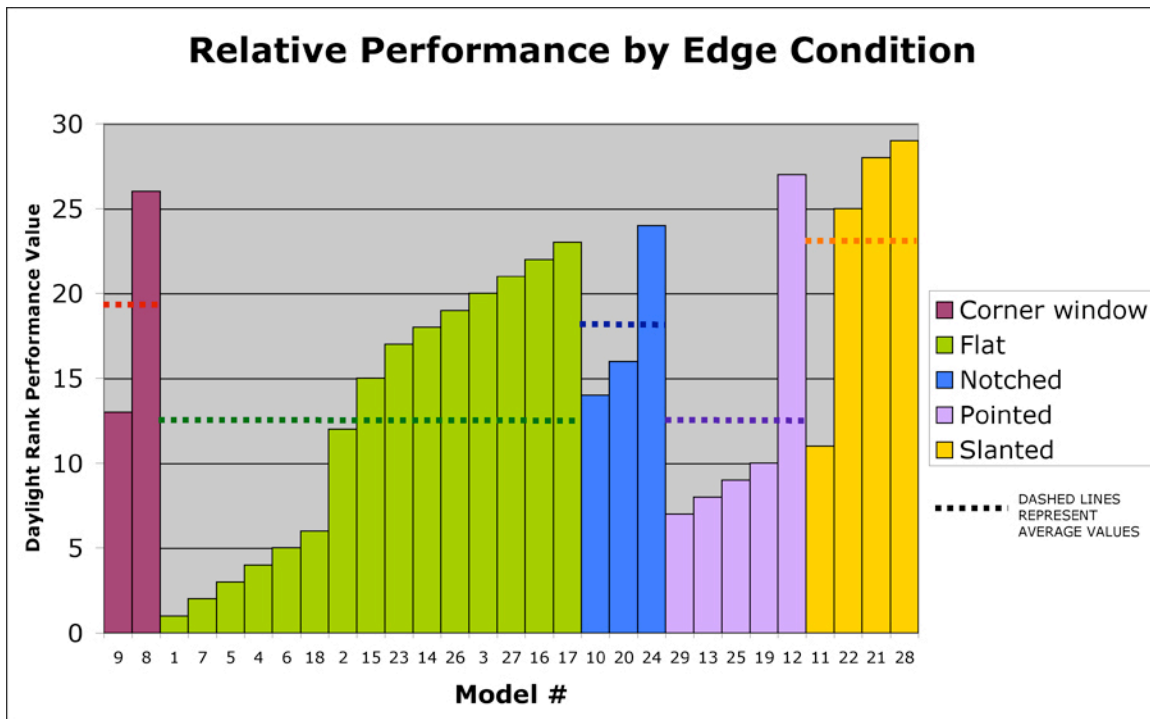


Figure 37 - Model performance by edge condition. The "daylight rank performance value" is 30 minus the daylight rank number. The relatively high performance of Model 8 is due to the use of translucent toilet walls. The relatively high performances of Models 24 & 12 are due to a combination of factors.

Figure 38 shows the daylight factor gradient (the highest measured d.f. minus the lowest) and the view potential by edge condition. The models with slanted or notched edges had the desirable attributes of large view potential and low daylight factor gradients. Those with pointed edges had good view potential, but high gradient values. These designs may be appropriate for long-term care facilities for the elderly, who typically need high illumination levels (250-300 f.c.) to maintain circadian rhythms.

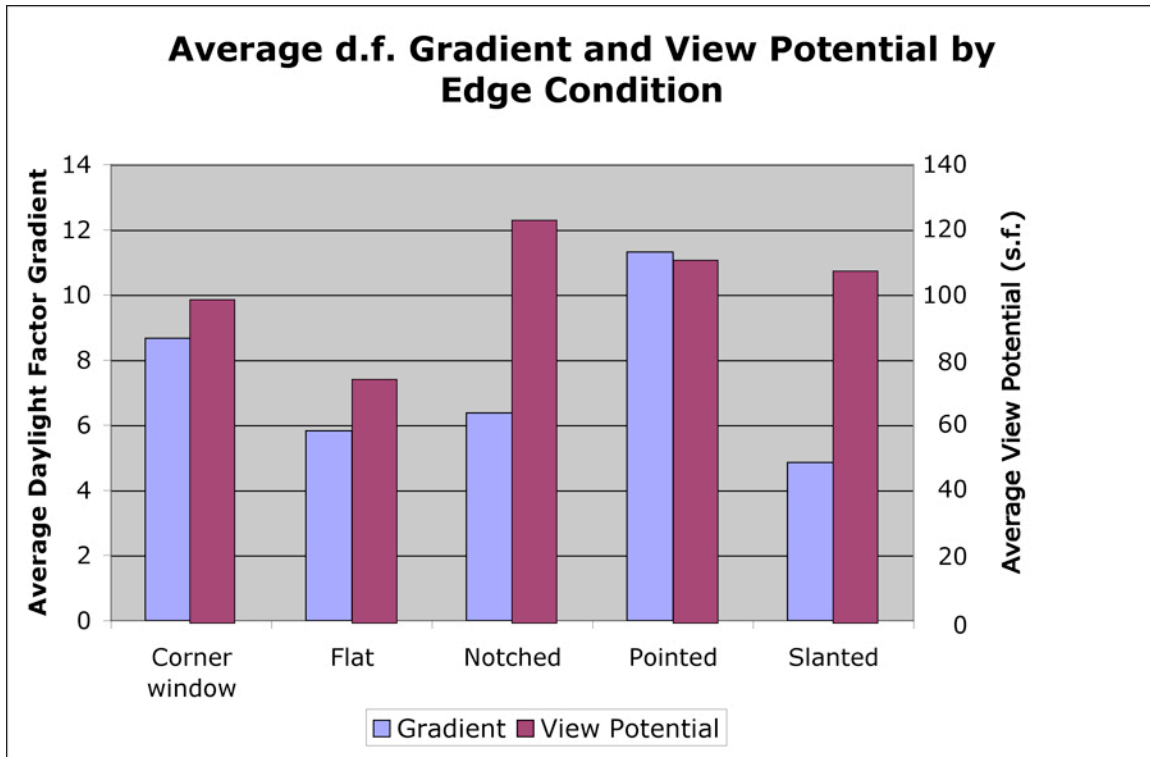


Figure 38 - Model daylight factor gradient and view potential by edge condition.

Ceiling Configuration

The performance of the ceiling configuration was closely tied to other morphological factors such as sill height and edge condition. Overall, rooms with slanted ceilings had deeper daylight penetration. It was assumed that the daylight windows ran from the defined sill height (6' or 8') to the top of the outer wall. Therefore, rooms with a lower sill height and a high ceiling height at the outer wall (i.e. those with slanted ceilings and/or high floor-to-floor heights) had much larger daylight windows and consequently higher illumination levels. In a number of instances these rooms with larger daylight windows afforded by the slanted ceiling had very large overall intensity values and very large gradients. Consequently, these rooms fared relatively poorly in the overall daylight rankings. Slanted ceilings appear to be best used in rooms with higher sills so that the daylight factor levels do not significantly exceed the target value of 2 and there is not a large gradient across the room.

Figure 39 shows the performance of the models by ceiling configuration. The y-axis represents the “daylight rank performance value,” which is the daylight rank number subtracted from 30. This metric was used in order to provide a higher value for better-performing models. As the chart indicates, the models with slanted ceilings tended to have the best performance, while those with flat ceilings tended to have lower rankings.

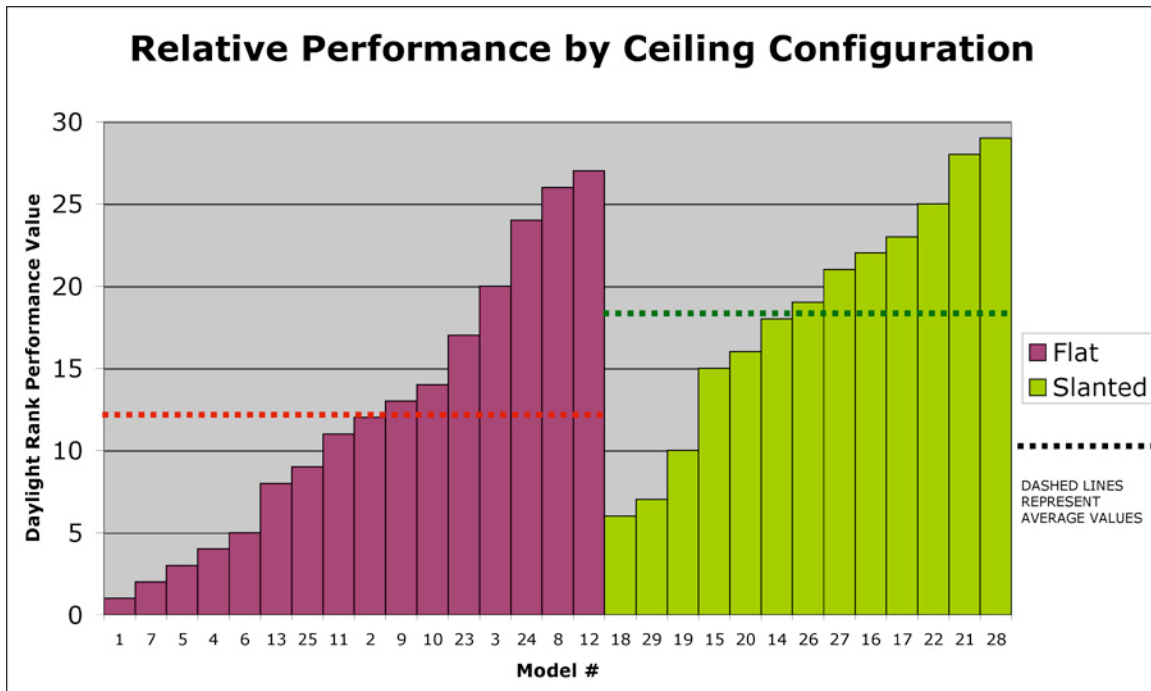


Figure 39 - Model performance by ceiling configuration. The "daylight rank performance value" is 30 minus the daylight rank number.

Figure 40 shows the average values for the daylight factor at the rear of the room by ceiling configuration. The models with slanted ceilings tended to have higher daylight penetration than those with flat ceilings.

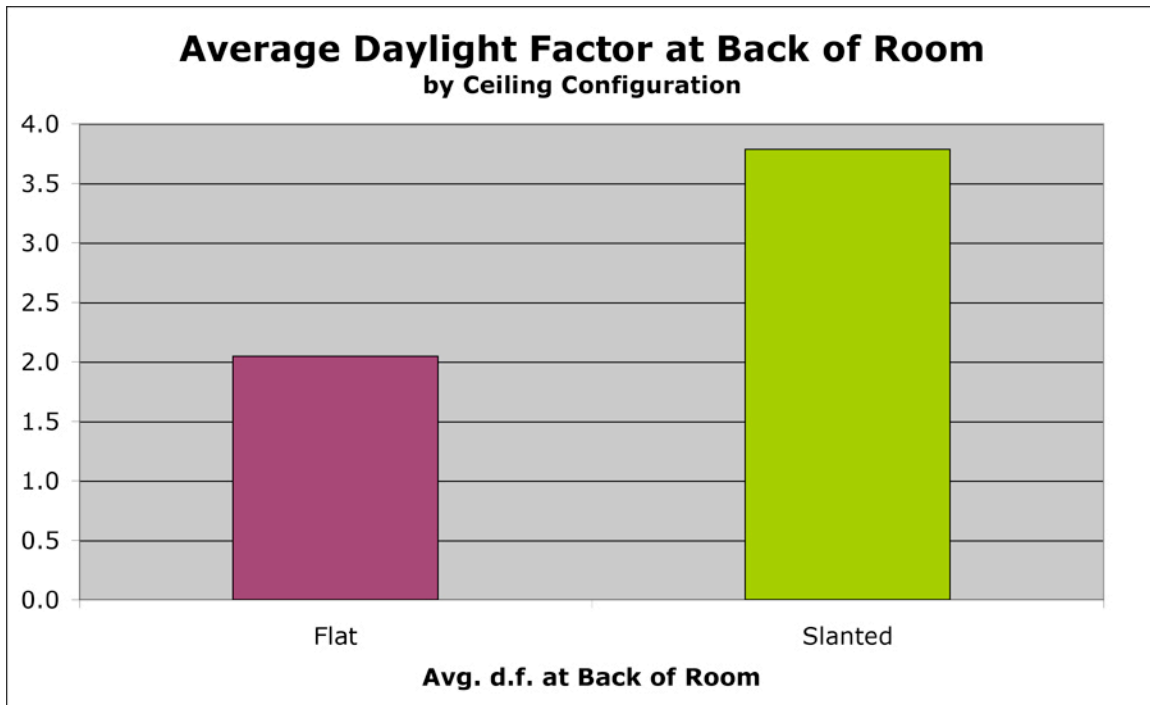


Figure 40 - Average model daylight factor at the back of the room by ceiling configuration

Room Dimensions

As with the ceiling configuration, the effect of varying room dimensions on daylight performance is closely tied to other morphological factors. However, some simple generalizations can be made.

Rooms with greater widths generally had higher light levels and deeper daylight penetration. This was usually due to the increased daylight glazing area afforded by wider rooms that did not have an outboard toilet. However, many of the wider rooms tested had unacceptably high light levels. Consequently, care must be taken to ensure that the daylight glazing is not too large in rooms with large outboard walls (i.e. wide rooms, rooms with non-flat edge conditions, etc.).

Figure 41 shows the average overall daylight factor and average daylight factor at the back of the room by width. As the chart indicates, rooms 16' wide tended to have higher illumination levels and better daylight penetration than narrower rooms.

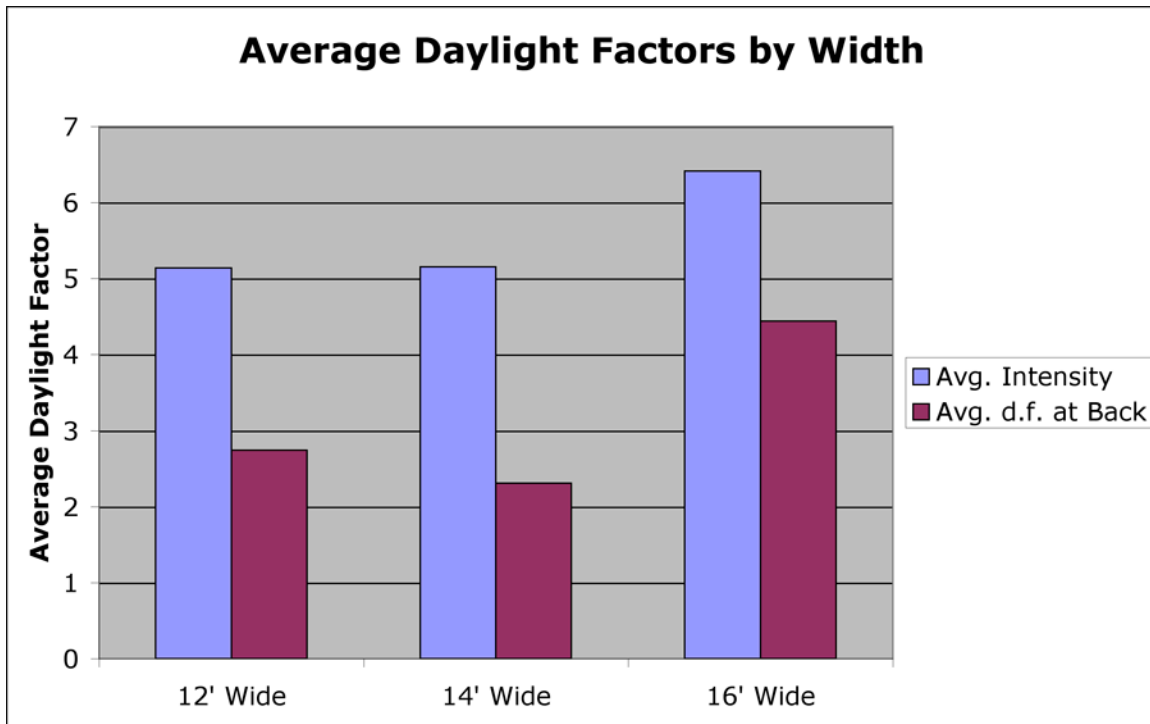


Figure 41 - Average model daylight factors by width. The relatively low average value d.f. at the back of the room for the 14' wide category was due to the inclusion of Model 1, which had an outboard toilet and very poor daylighting performance.

Not surprisingly, rooms with relatively shallow plans had better daylighting at the back of the room. Deeper rooms of similar configuration (i.e. width, height, etc.) had lower levels of daylight at the back of the room, with a fairly noticeable gradient drop-off towards the back. Note that the daylighting characteristics for deep and shallow rooms of similar configuration were nearly identical at the outer wall.

Figure 42 shows the average overall daylight factor and average daylight factor at the back of the room by depth. As the chart indicates, deeper rooms tended to have lower overall daylight factors and lower daylight factors at the back of the room than did shallower rooms.

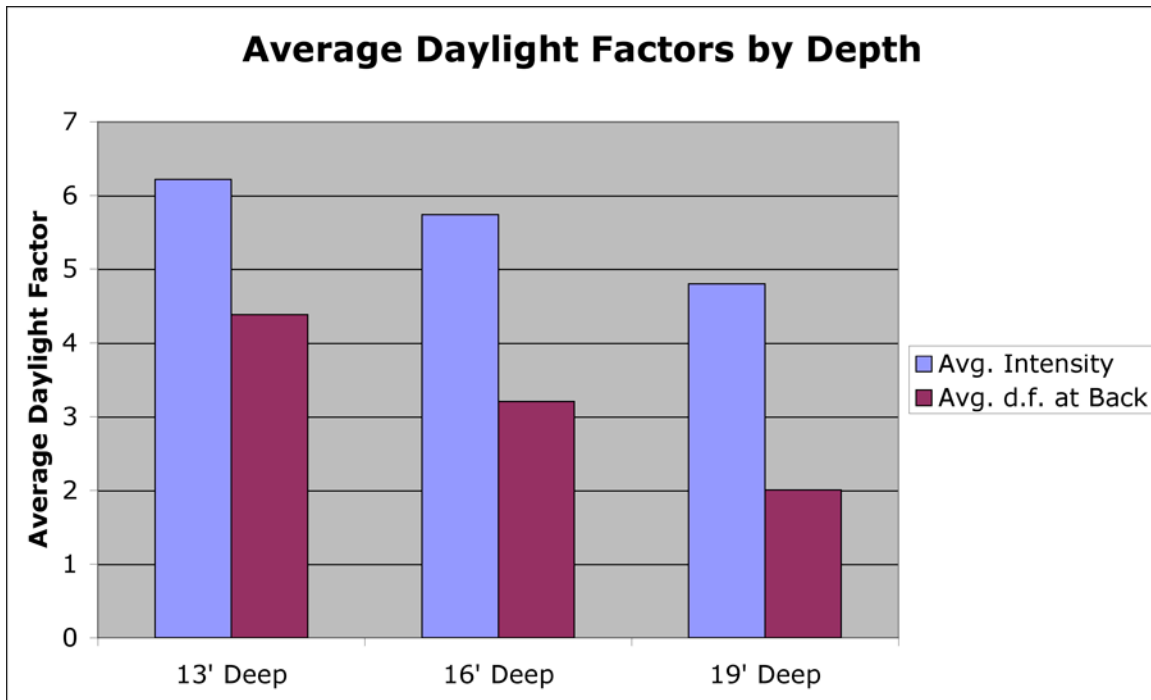


Figure 42 - Average model daylight factors by depth

Rooms with higher ceilings tended to have higher overall light levels and deeper daylight penetration. As with the wide rooms, this is most likely due to increased daylight glazing area. Similarly, there were a number of instances where the light levels were relatively high or the gradients fairly pronounced; again, overly large daylight glazing should be avoided.

Figure 43 shows the average overall daylight factor and average daylight factor at the back of the room by ceiling height. As the chart indicates, rooms with 10' ceilings tended to have better overall daylight values and better daylight penetration than those with shorter ceilings.

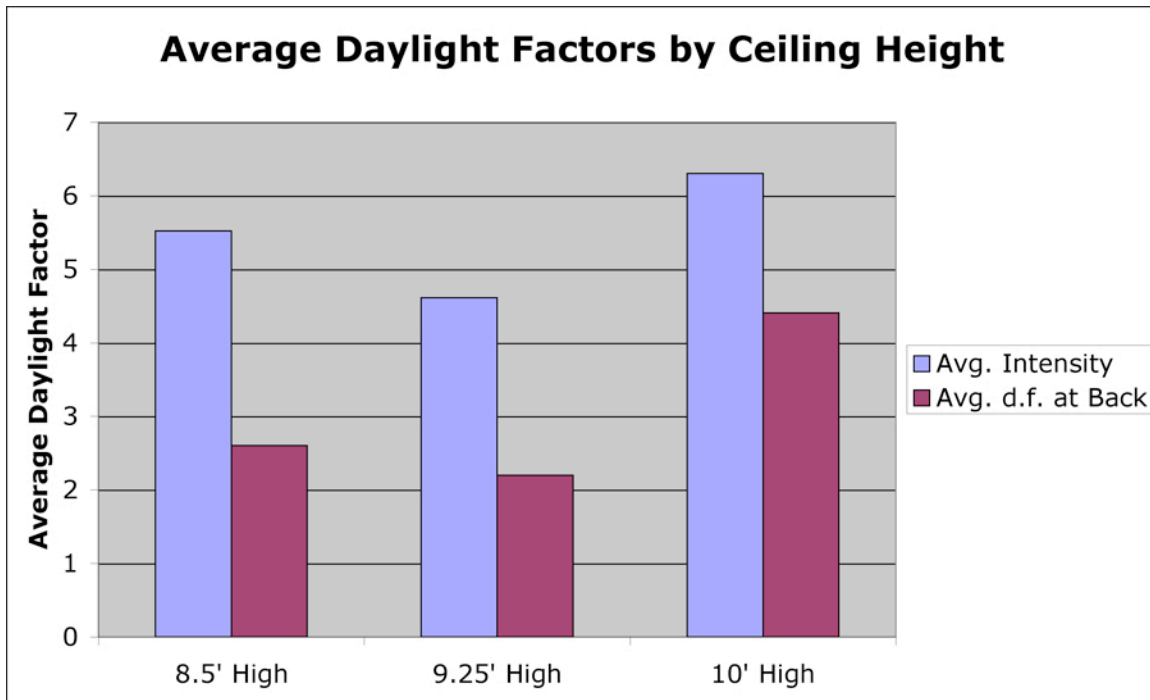


Figure 43 - Average model daylight factors by ceiling height

4.3 TESTING RESULTS SUMMARY

The results of the physical testing provided further insights into how the physical characteristics of the patient room affect the daylighting attributes. Based on the observations of the previous section, it was possible to summarize the effects of various physical configurations on the daylighting performance:

- Rooms with outboard toilets should be avoided; these produced consistently poor results. If an outboard toilet cannot be avoided, the designer should consider locating a window in the toilet room and using a translucent material for the toilet room walls.
- Glazing area is a key issue in attaining suitable levels of daylight in hospital rooms. While certain configurations such as wide rooms, high or slanted ceilings, and edge conditions that wrap around the corner allow for large glazing areas and view areas, care should be taken to avoid daylight glazing that introduces unacceptably high levels of solar energy gain. In these situations, using higher sills for the daylight windows generally resulted in more suitable daylight levels.
- Since many of the morphological factors considered work synergistically with each other, it is difficult to isolate the performance of a single factor. However, certain combinations of morphological factors have predictable characteristics:
 - Good performance was obtained from deep rooms with small widths that had a slanted outer wall and a slanted ceiling. This combination of factors allowed a

daylight window that got wider as it receded from the back of the room, which kept light levels relatively consistent across the room and provided a generous view opportunity. Three of the top five ranked rooms (Models 28, 21 and, 22) had these characteristics.

- Rooms with pointed edge conditions, low sills and/or slanted ceilings generally had bright spots and steep daylight level gradients that were considered to be poor performance.
- Rooms with inboard toilets and asymmetrical edge conditions had asymmetrical daylight contours, which may be of concern to the designer.

4.4 ELECTRIC SAVINGS

Based on the results of the testing, an analysis was performed to determine the percentage of electric savings based on daylighting. The percentage values are based on comparison to a room that had no daylighting, i.e. that was entirely lit by electric fixtures. Obviously, these values represent the reduction in electric lighting use during daylight hours only. The values were calculated based on the average d.f. values across the floor of the models, with a target illumination value of 30 footcandles. A minimum dimming level of 10% was assumed.

Figure 44 shows a bar chart of performance in this category by model number. Caution should be exercised in evaluating this ranking category in that only the savings due to electric lighting reduction was considered. Consequently, designs with relatively high rankings in this category may be overlit or result in excessive thermal heat gains/losses due to large glazing areas.

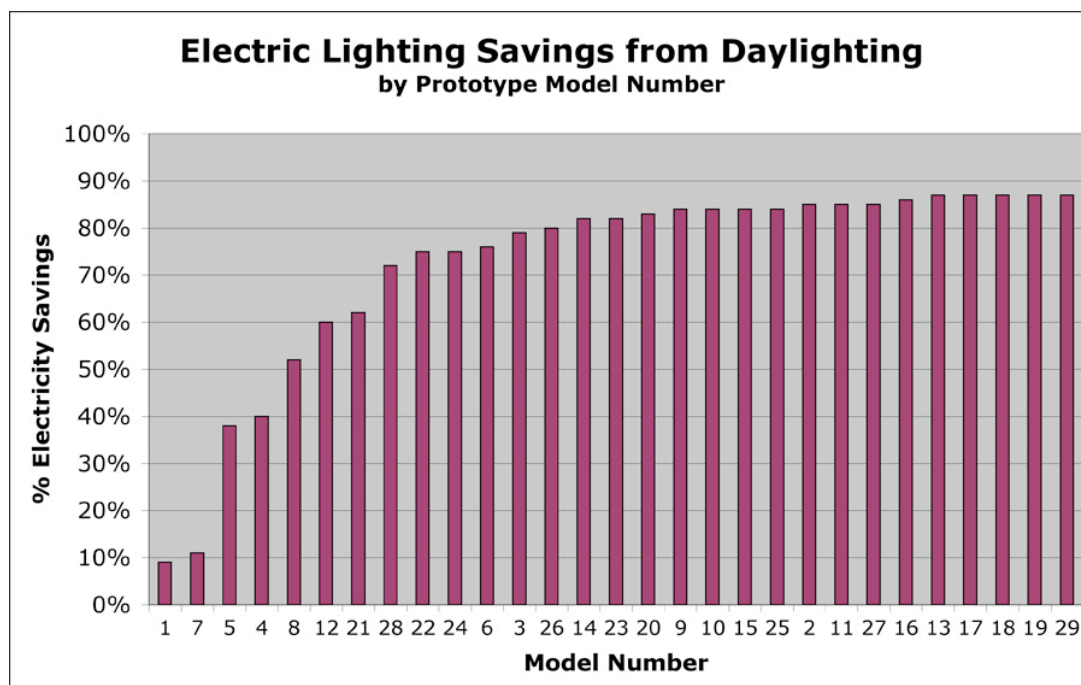


Figure 44 - Comparison of electric savings due to daylighting by model

The dollar value of the electric savings per room can be calculated based on the percentage of energy savings. Since electricity use will vary based on the size of the room, an energy density value of 0.7 W/s.f. was used. This value was based on engineering estimates used for current lighting system design. From this information, the annual energy consumption and subsequent savings were calculated. Figure 45 lists estimated cost savings by room type. The annual dollar savings per room was calculated based on a rate of \$0.045 per kilowatt-hour. The values for the 29 models tested ranged from \$3.16 to \$35.23.

Prototype	S.F.	Power (W)	Daylight Use (hr)	Daylight Power Use (kWh)	Annual Use (kWh)	% Reduction	Annual kWh Savings	Annual \$ Savings
1	266	186.2	12	2.2344	815.556	9%	73.4	\$3.30
2	266	186.2	12	2.2344	815.556	85%	693.2	\$31.20
3	266	186.2	12	2.2344	815.556	79%	644.3	\$28.99
4	266	186.2	12	2.2344	815.556	40%	326.2	\$14.68
5	266	186.2	12	2.2344	815.556	38%	309.9	\$13.95
6	228	159.6	12	1.9152	699.048	76%	531.3	\$23.91
7	208	145.6	12	1.7472	637.728	11%	70.2	\$3.16
8	208	145.6	12	1.7472	637.728	52%	331.6	\$14.92
9	304	212.8	12	2.5536	932.064	84%	782.9	\$35.23
10	224	156.8	12	1.8816	686.784	84%	576.9	\$25.96
11	266	186.2	12	2.2344	815.556	85%	693.2	\$31.20
12	266	186.2	12	2.2344	815.556	60%	489.3	\$22.02
13	182	127.4	12	1.5288	558.012	87%	485.5	\$21.85
14	266	186.2	12	2.2344	815.556	82%	668.8	\$30.09
15	266	186.2	12	2.2344	815.556	84%	685.1	\$30.83
16	256	179.2	12	2.1504	784.896	86%	675.0	\$30.38
17	208	145.6	12	1.7472	637.728	87%	554.8	\$24.97
18	228	159.6	12	1.9152	699.048	87%	608.2	\$27.37
19	224	156.8	12	1.8816	686.784	87%	597.5	\$26.89
20	192	134.4	12	1.6128	588.672	83%	488.6	\$21.99
21	224	156.8	12	1.8816	686.784	62%	425.8	\$19.16
22	224	156.8	12	1.8816	686.784	75%	515.1	\$23.18
23	228	159.6	12	1.9152	699.048	82%	573.2	\$25.79
24	168	117.6	12	1.4112	515.088	75%	386.3	\$17.38
25	192	134.4	12	1.6128	588.672	84%	494.5	\$22.25
26	228	159.6	12	1.9152	699.048	80%	559.2	\$25.17
27	192	134.4	12	1.6128	588.672	85%	500.4	\$22.52
28	192	134.4	12	1.6128	588.672	72%	423.8	\$19.07

Figure 45 - Table of annual dollar savings estimates by room. Values are based on an estimated energy density of 0.7 W/s.f. and a rate of \$0.045/kWh. Highlighted yellow entries correspond with “Top 10” designs.

5.0 BARRIERS TO CHANGE

There are a number of barriers to implementing the design suggestions that are outlined here. These barriers largely reflect prevalent attitudes in the healthcare and design communities. One of the largest barriers to flexibility in patient room layout is caregiver preference for outboard toilets. Generally, caregivers prefer outboard toilet rooms, because they allow for maximum visibility into the room. Given the increasing emphasis on allowing new hospital rooms to be easily convertible into critical care rooms, patient visibility is of the utmost importance. In

response to this concern, the use of shared-wall toilets should offer a suitable compromise, because they allow for ample views into the rooms from the corridor as well as allowing adequate daylighting.

However, the use of shared-wall toilets raises other objections because the design of a pair of shared-wall rooms inherently creates two different room layouts by having the entry to the toilet rooms in two different places. Figure 46 shows an example of this type of layout. In panel discussions with designers, caregivers have expressed a dislike for the fact that the two adjoining rooms have different floor plans. They find this distracting and an impediment to work as it interferes with their routine as they move from room to room. By laying out the room so as to minimize changes in location of the sinks, work surfaces, etc., the disruption to caregiver routines may be minimized.

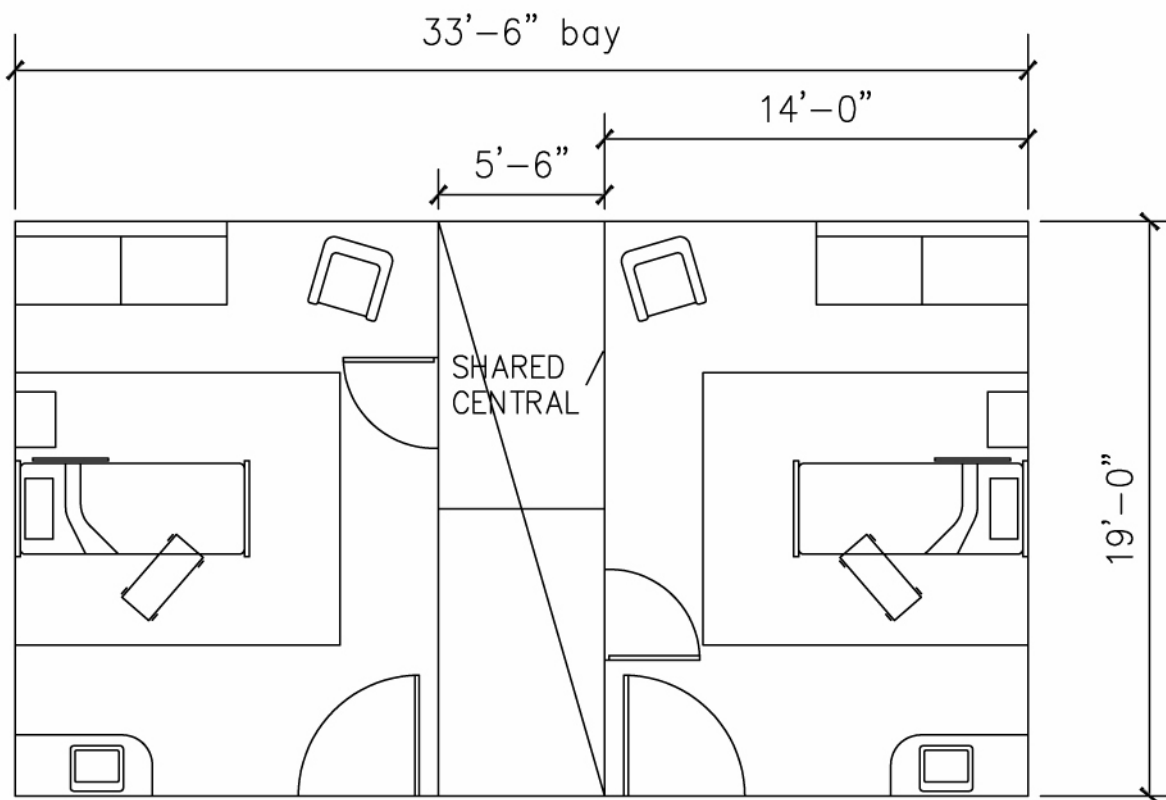


Figure 46 – Pair of shared-wall toilet rooms, showing different toilet door locations and "mirror image" layouts

Another concern raised by caregivers in discussions with designers involves potential interactions between caregivers and family members and other visitors. Caregivers prefer to minimize their contact with visitors in order to avoid disruptions to their busy schedules. Consequently, they prefer to have the caregiver zone separated from the family zone in order to minimize potential disruptions. However, this zoning restriction severely limits flexibility in

room design, with attendant problems in daylighting. Allowing for changes in traditional zoning patterns will be necessary to allow for the greatest flexibility in room design.

6.0 TOOL FOR DESIGNING DAYLIT PATIENT ROOMS

Based on the results of the model testing, a tool was developed to allow designers to get approximate results for daylight values in the back of the room. Figure 47 shows a nomograph that simulates the results of the daylight model testing. To use the nomograph, one enters from the top of the upper left panel, choosing a value for the room width and projecting down to the line for the appropriate room depth. From there, a line is projected to the next panel to the appropriate window head height, and reflected down to the sill height. From the appropriate sill height, the line is reflected over to the toilet type in the final panel and reflected down to the x-axis to read off the estimated value for the daylight factor in the back of the room. Note that the outboard toilet is not included on this chart as it is not recommended for adequate patient room daylighting. The red line gives an example for Model 3, a room with a 14' width, a 19' depth, a window head height of 9.25', a sill height of 6', and a toilet room located in the inboard position. The resulting d.f. estimate is approximately 2.4 (c.f. tested value of 2.2). In order to obtain higher final d.f. values, it is best to choose options corresponding to lines either higher or further to the right on each respective panel.

Daylight Factor Estimation Nomograph

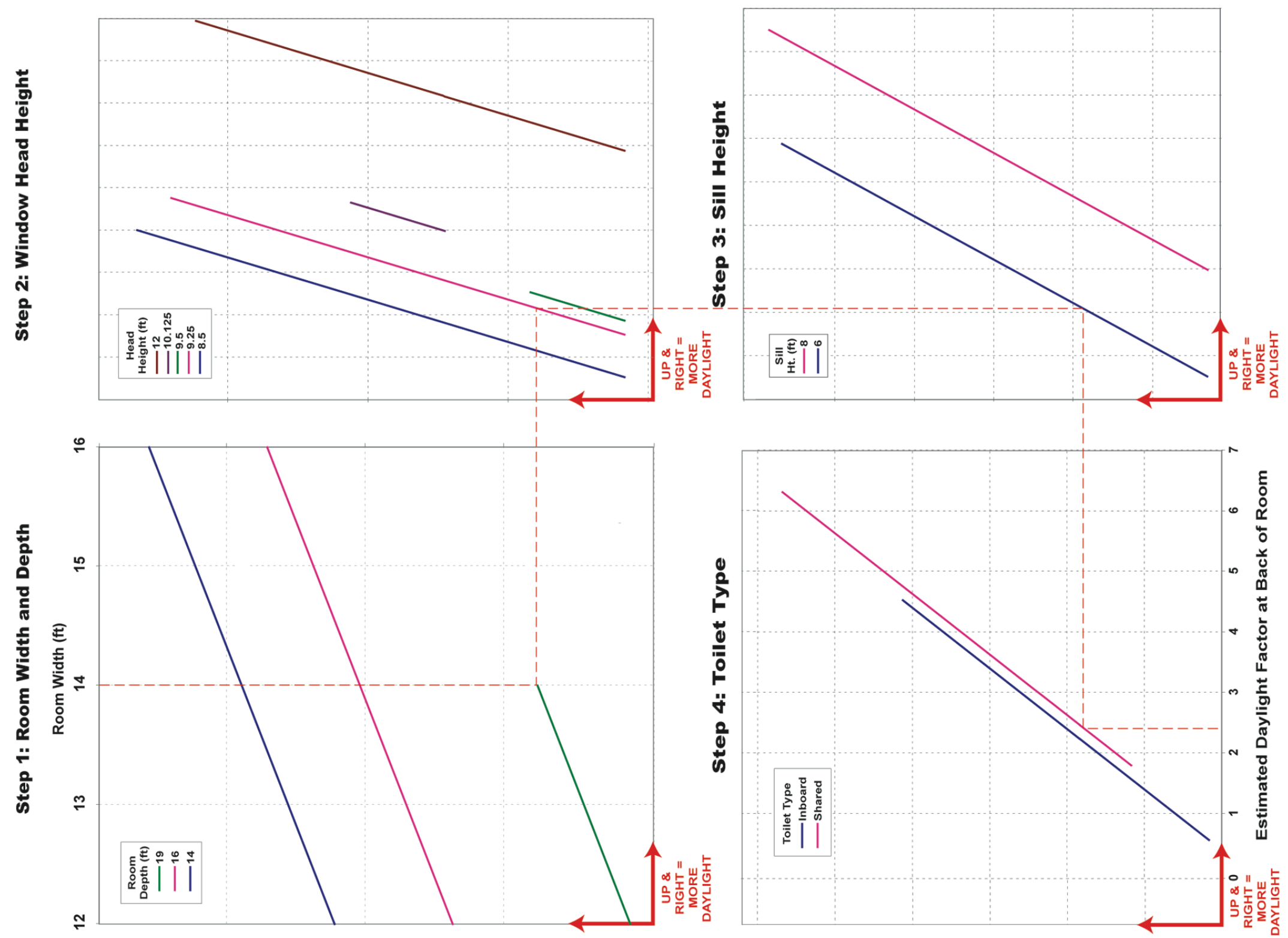


Figure 47 - Nomograph for preliminary room design and daylight factor estimation. The red line gives a sample estimation for Model3. See section 6.0 for a detailed explanation on how to use the nomograph.

Appendix A – Bibliography with Annotations

Following is a bibliography of research materials used while compiling this paper. Some of the entries have annotations summarizing the content of the source as well as a subjective scale of relevance to the environmental or daylight aspects of the source. This rating is on a scale of 1 to 5, with 1 being only marginally related to the topic of daylighting or patient well-being, and 5 being very relevant to these topics.

Abercrombie, Stanley, “Design + Health,” *Interior Design*, August 1993, vol. 64, num. 8, pp.78-83.

Environment/Daylighting Relevance: 1

This article provides a very general overview of the history of healthcare design and touches briefly on perceived trends such as “hotel-ization” of healthcare facilities.

Adams, A. and Theodore, D, “Medicine by Design,” *Canadian Architect*, March 2002, vol. 47, num. 3, pp.14-15.

Environment/Daylighting Relevance: 1

This article provides a short, general overview of Canadian healthcare architecture since the Second World War. The main focus seems to be a concern that new “superhospitals,” such as the proposed 3,000,000 s.f. McGill University Health Center, do not adequately take into consideration their community context. While not dealing specifically with daylighting or spatial composition, it does provide a potentially useful link to McGill University’s Medicine By Design website: <http://www.mcgill.ca/arch/mbd>.

Allison, D.J. (Ed.), *Planning, Design, and Construction of Health Care Environments*, Oakbrook Terrace, IL: Joint Commission, 1997.

American Institute of Architects, *Guidelines for Design and Construction of Hospital and Health Care Facilities*, Washington D.C.: American Institute of Architects, 2001.

Appleton, Jay, *The Experience of Landscape*, New York: John Wiley & Sons, 1996.

Bobrow, T. and Thomas, J., *Humanizing the Institution: the Architecture of Bobrow/Thomas and Associates*, New York : Edizioni Press, Inc., 2002.

Boubekri, M., Hulliv, R.B., and Boyer, L.L., “Impact of Window Size and Sunlight Penetration on Office Workers’ Mood and Satisfaction: A Novel Way of Assessing Sunlight,” *Environment and Behavior*, July 1991, vol. 23, num.4, pp. 474-493.

Environment/Daylighting Relevance: 5

This article gives the results of an experiment in which the emotional responses to sunlight penetration were measured with a sample of office workers. An experiment was conducted in which the window size, location, and sunlight penetration (defined as the ratio of sunlit area to floor area) was measured based on response to a survey. Statistical analysis on the results led to the conclusion that the highest levels of relaxation occurred when the sunlight penetration was between 15%-25%. Penetration over this amount was considered to be too bright and uncomfortable, resulting in lower levels of relaxation.

Carmody, J., Selkowitz, S., Lee, E.S., Arasteh, D., and Willmert, T., *Window Systems for High-Performance Buildings*, New York: W.W. Norton & Company, Inc., 2004.

Devlin, A.S. and Arneill, A., “Health Care Environments and Patient Outcomes: A Review of the Literature,” *Environment and Behavior*, September 2003, vol. 35, num. 5, pp.665-694.

Environment/Daylighting Relevance: 3

This is an overview of a variety of sources of contemporary healthcare facility design issues. As such, it touches on environment and daylighting, but only as part of a larger whole. It does, however, provide a sizable bibliography and some interesting findings. One such finding is that a window size equal to 20—30% of the window wall had good results in improving patient psychological well-being.

Flanagan, Barbara, “Design Cures,” *Metropolis*, December 2000, vol. 20, num. 4, pp.65-73, 101.

Environment/Daylighting Relevance: 1

This article deals more with the emergence of market-driven architecture (“marchitecture”) in health care. Given that consumers have more choices in choosing healthcare facilities, hospitals and other institutions are trying to be more consumer-friendly in order to attract new patients and encourage repeated use. Design strategies such as “identifying” with shopping malls and health clubs or designing patient and recovery rooms to have homier touches tend to make patients feel more comfortable. The one nod to design and patient recovery has to do with designing facilities that will encourage family members to visit, as this has been shown to help facilitate the recovery process.

Gallup, Joan Whaley, *Wellness Centers: A Guide for the Design Professional*, New York: John Wiley & Sons, 1999.

Environment/Daylighting Relevance: 1

This is a good reference for “wellness centers,” with specific design recommendations for lighting levels and suggested fixture types. However, it doesn’t have much bearing on hospital rooms, being more appropriate as a guide for health spa lighting.

Hopkinson, R.G., Petherbridge, P., and Longmore, J., *Daylighting*, London: William Heinemann Ltd., 1966.

IESNA RP-28-98, *Lighting and the Visual Environment for Senior Living*, New York: Illuminating Engineering Society of North America, 1998.

Kliment, Stephen (ed.), *Building Type Basics for Healthcare Facilities*, New York: John Wiley & Sons, Inc, 2000.

Marberry, Sara O. (ed.), *Innovations in Healthcare Design*, New York: John Wiley & Sons, 1995.

Environment/Daylighting Relevance: 2

This reference has few qualitative recommendations regarding daylighting and healthcare design. However, it does mention the need for daylighting in such spaces, citing the need for daylight for absorption of calcium and phosphorus for bone growth, reduction of stress hormones, and controlling viral and staph infections.

McCormick, M. and Shepley, M.M., “How Can Consumers Benefit from Therapeutic Environments?” *Journal of Architectural and Planning Research*, Spring 2003, vol. 20, num. 1, pp.4-15.

Environment/Daylighting Relevance: 1

This is an overview of other articles in this issue, some of which are cited in this bibliography. No relevant information is contained in this article.

Nesmith, Eleanor Lynn, *Health Care Architecture: Designs for the Future*, Rockport, Mass: Rockport Publishers, Inc., 1995.

Noell-Waggoner, Eunice, *Let There Be Light, or Facing the Consequences: A National Concern for our Aging Population*, unpublished paper, 2003.

Rea, Mark S. (ed.), *The IESNA Lighting Handbook: Reference and Application*, New York: the Illuminating Engineering Society of North America, 2000.

Rosenfield, Isadore, “Daylighting for Hospitals,” *Pencil Points*, December 1945, v. 26, pp. 92-96; February 1946, pp. 87-91.

Environment/Daylighting Relevance: 3

This is more of an overall review of basic daylighting concepts rather than an extensive survey of the use of daylighting in hospitals. There is a brief discussion of the germicidal potential of daylight, but at the time this article was written the bacteriological data was far from complete. Overall, the author's stance was that more glass was better in a hospital environment, provided that the spaces would not get overheated.

Ulrich, R.S., “View Through a Window May Influence Recovery from Surgery,” *Science*, 27 April 1984, vol. 224, pp. 420-1.

Environment/Daylighting Relevance: 4

This article describes the results of a statistical analysis of recovery issues in a Pennsylvania hospital. The patients studied were recovering from the same type of surgery and were housed in the same wing of the hospital. All patients had an unobstructed view of a window 1.83m high by 1.22m wide, located 0.74m from the floor. Half of the patients had a view of a small stand of trees while the other half's view consisted of a brown brick wall. A robust statistical analysis of the data showed that the patients with the tree view spent less time in the hospital while recovering from the surgery and also took fewer moderate and strong doses of pain medication. The overall conclusion was that the unobstructed view of a natural scene had a statistically recognizable therapeutic effect.

Ulrich, R.S., “How Design Impacts Wellness,” *Healthcare Forum Journal*, September-October 1992, vol. 35, pp. 20-5.

Environment/Daylighting Relevance: 3

This article primarily recaps the points made in Ulrich's other writings, particularly the stress-relieving properties of natural scenes. An interesting point made is that many of the users of healthcare facilities – doctors and visitors as well as patients – are over the age of 65. Consequently, design considerations should be made for these “aging” users. With respect to lighting, this means taking steps to reduce glare and provide flexibility in lighting options, particularly in bedrooms.

Ulrich, R.S., "A Theory of Supportive Design for Healthcare Facilities," *Journal of Healthcare Design*, 1997, vol. 9, pp. 3-7, 21-4.

Environment/Daylighting Relevance: 2

This an introduction to a symposium on the built environment in healthcare design. The author gives an overview of the evolution and current thinking regarding this topic. Whereas previously the design trend had been towards functional efficiency in providing delivery of healthcare technology, there is now an emerging trend towards creating an environment that will result in a beneficial psychological effect for the patient, visitor and healthcare provider. The three main guidelines for achieving this are: providing a sense of control for the physical surroundings, access to social support, and access to positive distractions. Regarding this final point, the author advocates providing views to spatially open natural environments and cites studies in which such views have been shown to positively affect patient recovery.

Ulrich, R.S., "Effects of Gardens on Health Outcomes: Theory and Research," in *Healing Gardens: Therapeutic Benefits and Design Recommendations*, New York: John Wiley & Sons, 1999, pp. 27-86.

Environment/Daylighting Relevance: 4

This extensive article by Roger Ulrich is part of a larger collection of works regarding the design and effect of healing gardens. While Ulrich's article pertains mainly to the restorative effects of nature settings, it does allow for amplification on theories and studies that views of natural settings have been statistically proven to promote patient well-being. Also, this is one of the very few articles that mentions the possible ill-effects of glare from windows and the potential for adverse effects from too much exposure to sunlight (i.e. for patients on medication that makes them too sensitive to light).

Ulrich, R.S., Simons, R.F., Miles, M.A., "Effects of Environmental Simulations and Television on Blood Donor Stress," *Journal of Architectural and Planning Research*, Spring 2003, vol. 20, num. 1, pp.38-47.

Environment/Daylighting Relevance: 2

This article deals with the results of an experiment performed on blood bank donors in which they were exposed to one of four stimuli before and during blood donation: a videotape of natural scenes, a videotape of urban scenes, regular daytime television programming, and a blank screen (TV turned off). Based on blood pressure readings and incidents of fainting, it was determined that the nature scenes were considered less stressful than the urban scenes, and that the turned-off TV was less stressful than the daytime programming.

Verderber, Stephen, "Designing for the Therapeutic Functions of Windows in the Hospital Rehabilitation Environment," *Proceedings of the Thirteenth International Conference of the Environmental Design Research Association*, 1982, pp. 476-492.

Environment/Daylighting Relevance: 5

This is a condensed version of the author's doctoral dissertation. It describes a detailed study that took place in the Physical Medicine and Rehabilitation units of six Chicago area hospitals. The study was based on exposure to six primary indices: window/wall ratios, sill height, view complexity, sunlight, patient/staff proximity to window, and screen use. Based on the results of the study, the author identifies thirteen design patterns: meaningful views, views of street life, perceptual access, daylight transmission, room spaciousness, functional sill height, vertical orientation, functional screening, prospect-refuge, indoor nature, surrogate views, media connection, and windows at home. Overall, the author concludes that having a meaningful view from the patient/staff area is more important than daylight transmission.

Verderber, Stephen, "Dimensions of Person-Window Transactions in the Hospital Environment," *Environment and Behavior*, July 1986, Vol. 18, Num. 4, pp. 450-466.

Environment/Daylighting Relevance: 5

This article conveys the results of a study in which patients were asked to evaluate a series of photographs of hospital rooms in order to rate their satisfaction with the scene or window configuration. High levels of preference were shown for windows that showed representations of nature and that allowed daylight into the building interior. Images of brightly daylit therapy rooms ranked highest in one of the test series. Also of interest was the result that dysfunctional windows (having high sills, distant from the viewer, or obscured by screens, walls or other objects) resulted in the same level of satisfaction as windowless rooms.

Verderber, S. and Reuman, D., "Windows, Views, and Health Status in Hospital Therapeutic Environments," *Journal of Architectural and Planning Research*, 1987, Vol. 4, Num. 2, pp. 120-133.

Environment/Daylighting Relevance: 5

This article relates the findings of a study done on six urban Chicago hospitals in regards to the perceived well-being of patients and staff based on their relationships with windows. All of the patients were hospitalized for an average of nearly two months. The study was based on patient records and questionnaires. Overall, the highest well-being was found in the respondents who were located in close proximity to a window (within 15 feet) with a low or moderate sill height (less than 36") and with a dynamic and interesting view.

Verderber, S. and Refuerzo, B.J., "On The Construction of Research-Based Design: A Community Health Center," *Journal of Architectural and Planning Research*, Autumn 1999, Vol. 16, Num. 3, pp. 225-241.

Environment/Daylighting Relevance: 2

This is an overview of the experience of the authors with a "research-based design" of a healthcare facility in rural Louisiana. The design guidelines were based on post-occupancy evaluations at a number of other similar facilities around the state. One of the top results of the POEs was a desire for natural daylight and room-to-room transparency. These were also given high marks by the users of the facilities that were designed based on these criteria.

Verderber, S. and Fine, D.J., *Healthcare Architecture In An Era of Radical Transformation*, New Haven: Yale University Press, 2000.

Environment/Daylighting Relevance: 4

This book is a good survey of contemporary thought on healthcare design. It also provides Verderber a forum to summarize (albeit briefly) some of the research he has done regarding windows, environment, and patient psychological states. The authors frequently invoke the ancient Greek concept of the Asclepia, which stressed patient healing through a connection to nature and the outdoors.

Zeisel, John, "Marketing Therapeutic Environments for Alzheimer's Care," *Journal of Architectural and Planning Research*, Spring 2003, vol. 20, num. 1, pp.75-86.

Environment/Daylighting Relevance: 2

While this article focuses on a treatment for a specific disease, and in marketing in particular, it does have some interesting insights into the importance of environment in helping treat medical disorders in general – notably, the notion of having the environment hold some interest for the patient. Where it had previously been thought that designing a bland and sedate environment would be soothing for the patient, it may in fact have the opposite effect. The challenge is to develop a design that provides sensory activity without being disconcerting. An example of this is

the use of patterned wallpaper – traditional patterns being preferred over abstract patterns, as they achieve the sensory interest without being confusing.

Zeng, H.H., *View, View Point & Size of the Window*, unpublished master's project, University of Oregon, Eugene, Oregon, 1999.

Appendix B – Detailed Test Matrix

Model #	Model	D.F. @ back	Rank	Toilet Type	Toilet Location	Width	Depth	Area	Ceiling Type	FTF Ht.	Ceiling Ht.	Structure	Plenum	Sill Height	Win. Head Ht.	Edge Type	Model Notes	Test Notes	Daylight Area (sf)	View Area (sf)
1	A	0.003	29	Shower stall	Outboard	14	19	266	Flat	14	9.25	2.5	2.25	8'	9.25	Flat	Typical ZGF design		5.50	46.50
2	A	2.361	18	Shower stall	Inboard	14	19	266	Flat	14	9.25	2.5	2.25	6'	9.25	Flat	Improved typ. ZGF design		40.50	80.50
3	A	2.157	10	Integrated shower	Shared wall	14	19	266	Flat	14	9.25	2.5	2.25	6'	9.25	Flat	Improved typ. ZGF design	Sensors on centralized grid	40.50	80.50
4	B	0.917	26	Shower stall	Outboard*	14	19	266	Flat	15	10	2.5	2.5	8'	10	Flat	*Shortened toilet walls		9.63	34.50
5	B	0.607	27	Shower stall	Outboard**	14	19	266	Flat	15	10	2.5	2.5	8'	10	Flat	**Translucent toilet walls	Both windows open	9.63	34.50
6	C	0.525	25	Shower stall	Inboard	12	19	228	Flat	13	8.5	2.5	2	6'	8.5	Flat	Worst-case scenario		25.88	69.00
7	D	0.082	28	Integrated shower	Outboard	12	16	192	Flat	14	9.25	2.5	2.25	8'	9.25	Flat	Compact room configuration		5.50	44.56
8	E	1.377	4	Shower stall	Outboard**	16	13	208	Flat	14	9.25	2.5	2.25	8'	9.25	Corner window	**Translucent toilet walls	Both windows open	13.75	108.50
9	F	2.757	17	Integrated shower	Outboard*	16	19	304	Flat	14	9.25	2.5	2.25	6'	9.25	Corner window	*Shortened toilet walls		46.50	90.56
10	G	4.211	16	Integrated shower	Shared wall	16	14	224	Flat	13	8.5	2.5	2	6'	8.5	Notched	Outer visitor zone		46.14	126.50
11	H	3.155	19	Shower stall	Inboard	14	19	266	Flat	14	9.25	2.5	2.25	6'	9.25	Slanted	Typical ZGF design w/ outer visitor zone		44.25	87.69
12	I	0.795	3	Tub room	Inboard	14	19	266	Flat	14	9.25	2.5	2.25	8'	9.25	Pointed	Typical ZGF design w/ outer visitor zone		17.50	143.38
13	I	6.436	22	Integrated shower	Shared wall	14	13	182	Flat	14	9.25	2.5	2.25	6'	9.25	Pointed	Compact w/ discrete zoning possibilities		52.50	106.38
14	J	2.457	12	Integrated shower	Shared wall	14	19	266	Slanted	12	7.75	2.5	1.75	6'	9.5	Flat	No perimeter beam; some external HVAC		43.88	80.50
15	J	1.784	15	Shower stall	Inboard	14	19	266	Slanted	12	7.75	2.5	1.75	6'	9.5	Flat	No perimeter beam; some external HVAC		43.88	80.50
16	K	6.278	8	Integrated shower	Shared wall	16	16	256	Slanted	15	10	2.5	2.5	8'	12.5	Flat	Wide room w/ good daylighting potential		65.88	124.00
17	L	7.570	7	Non-ADA	Inboard	16	13	208	Slanted	15	10	2.5	2.5	8'	12.5	Flat	Best-case scenario		65.88	124.00
18	M	6.358	24	Integrated shower	Shared wall	12	19	228	Slanted	15	10	2.5	2.5	6'	12.5	Flat	Deep room w/ good daylighting potential		71.88	69.00
19	N	4.180	20	Tub room	Inboard	14	16	224	Slanted	13	8.5	2.5	2	6'	9.75	Pointed	Outer visitor zone		67.82	106.38
20	O	4.053	14	Integrated shower	Shared wall	12	16	192	Slanted	15	10	2.5	2.5	8'	11.75	Notched	Discrete zoning possibilities		57.76	139.50
21	P	1.896	2	Integrated shower	Shared wall	14	16	224	Slanted	13	8.5	2.5	2	8'	10.125	Slanted	Moderate size w/ good daylighting potential		38.72	118.19
22	P	1.384	5	Shower stall	Inboard	14	16	224	Slanted	13	8.5	2.5	2	8'	10.125	Slanted	Moderate size w/ good daylighting potential		38.72	118.19
23	A2	2.288	13	Integrated shower	Shared wall	12	19	228	Flat	14	9.25	2.5	2.25	6'	9.25	Flat	Altered Model A	Revised version of Test 3	34.50	69.00
24	G2	2.311	6	Integrated shower	Shared wall	12	14	168	Flat	13	8.5	2.5	2	6'	8.5	Notched	Altered Model G	Revised version of Test 10	37.13	103.50
25	I2	2.778	21	Integrated shower	Shared wall	12	16	192	Flat	14	9.25	2.5	2.25	6'	9.25	Pointed	New model made	Revised version of Test 13	48.00	97.75
26	J2	1.881	11	Integrated shower	Shared wall	12	19	228	Slanted	12	7.75	2.5	1.75	6'	9.5	Flat	Altered Model J	Revised version of Test 14	37.38	69.00
27	K2	5.067	9	Integrated shower	Shared wall	12	16	192	Slanted	15	10	2.5	2.5	8'	12.5	Flat	Altered Model K	Revised version of Test 16	48.88	93.00
28	P2	2.087	1	Integrated shower	Shared wall	12	16	192	Slanted	13	8.5	2.5	2	8'	10.125	Slanted	Altered Model P	Revised version of Test 21	27.63	104.63
29	N2	4.213	23	Integrated shower	Inboard	14	16	224	Slanted	13	8.5	2.5	2	6'	10	Pointed	Altered Model N	Revised version of Test 19	67.82	106.38

Shower Stall - 8' x 8'6"
Non-ADA - 3' x 5'
Tub Room - 6' x 9'
Integrated Shower - 6'3" x 6'9"

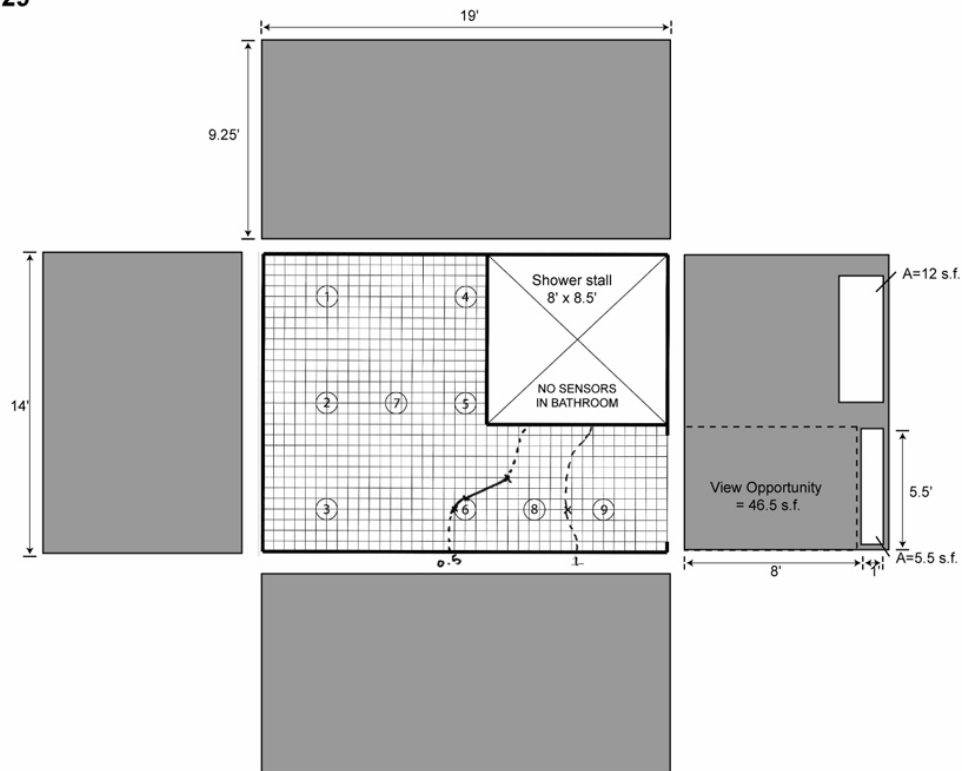
= changed from ori ginal matrix of 10/15/04
= changed from revised matrix of 12/04

Appendix C – Test Model Configurations & Daylight Factor Contours

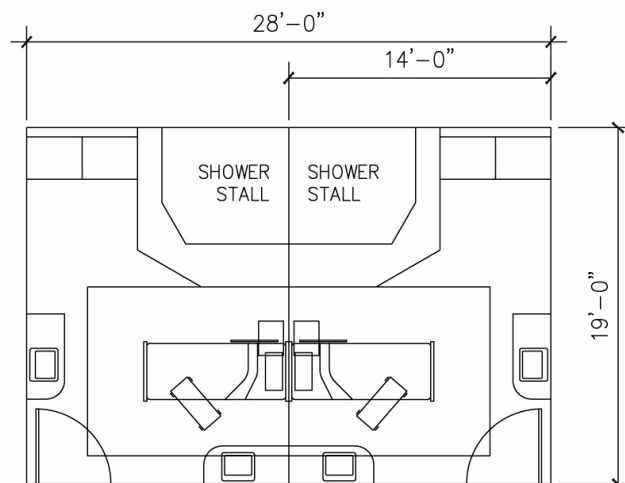
The following descriptions detail the test procedures and geometries of the 29 models tested, as well as the daylight factor contours obtained from testing. In some cases, more than one test was performed on a particular model - the variations in testing are noted in the test description.

ZGF Hospital Daylight Testing - Test 1

rank = 29

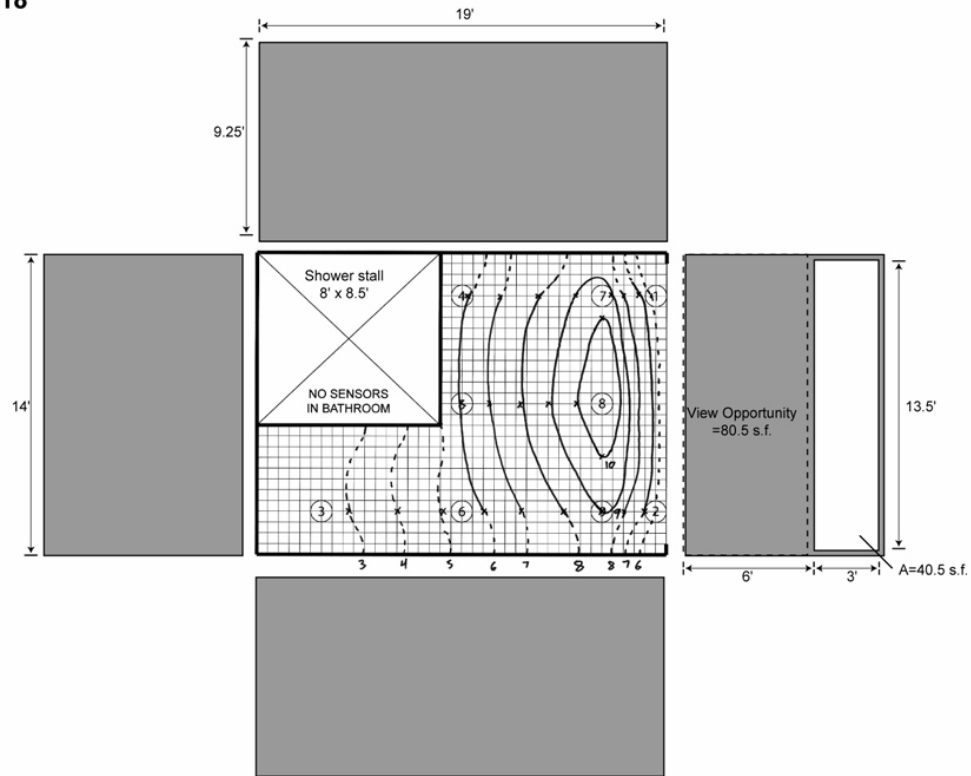


- Model 1** – This model represented a typical current hospital room design. The room measured 14' in width by 19' in depth, with a ceiling height of 9'3". The daylight window had an 8' sill height, with a total glazing area of 5.5 s.f. The view opportunity was 46.5 s.f. The glare constant from the daylight window (not including the toilet room window) was 86.

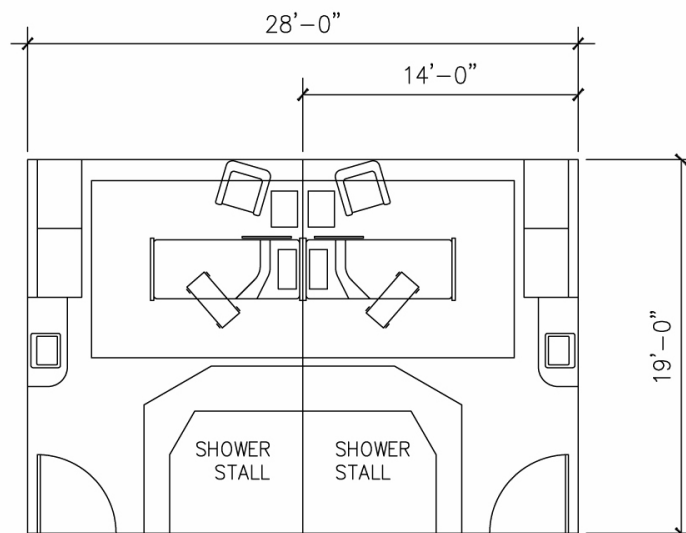


ZGF Hospital Daylight Testing - Test 2

rank = 18

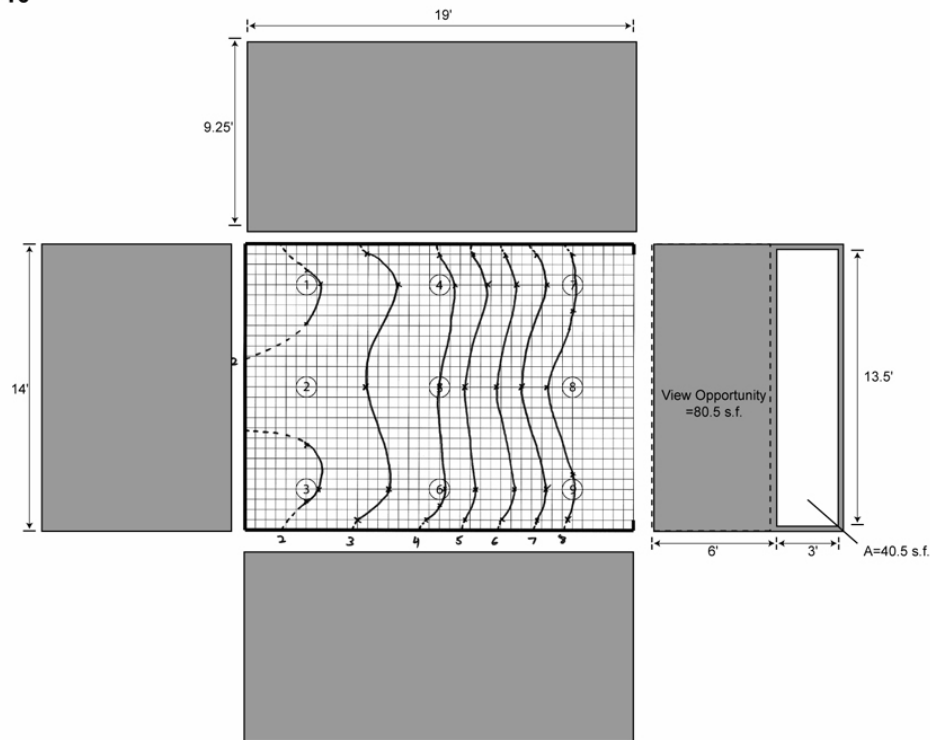


- Model 2** – The room configuration for this test was almost identical to that of Test 1, with the exception of the shower stall toilet room being located in the inboard position. The sill height of the daylight window was 6' and could stretch the entire length of the room, resulting in a glazing area of 40.5 s.f. and a view opportunity of 80.5 s.f. The glare constant from the daylight window was 143.



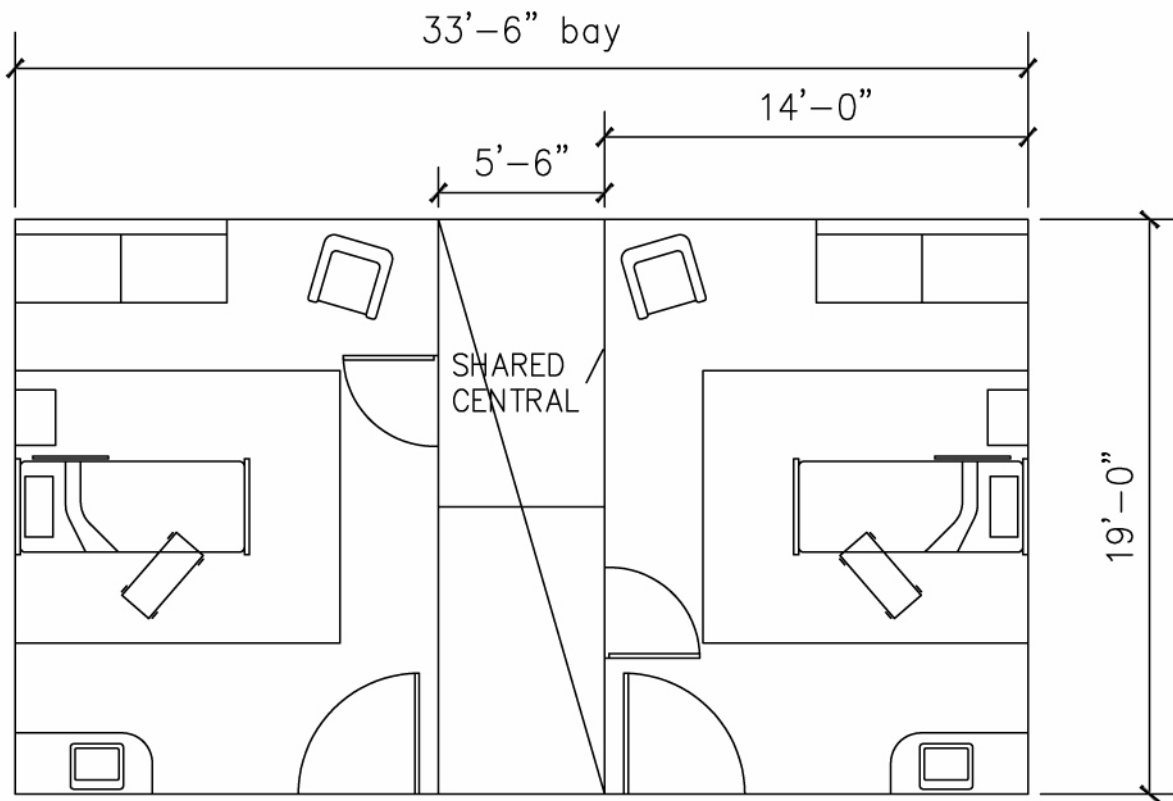
ZGF Hospital Daylight Testing - Test 3 (a&b combined)

rank = 10



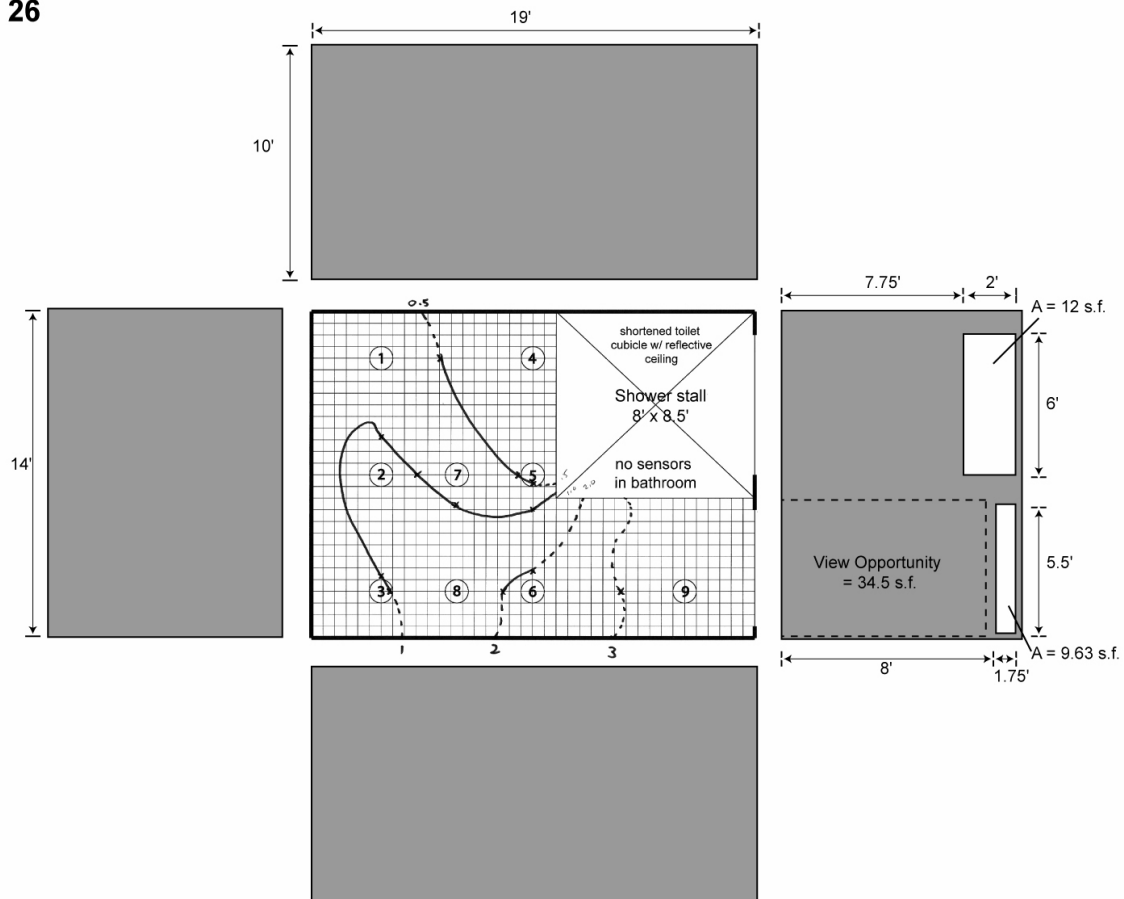
- **Model 3** – This room configuration was identical to that of Model 2, with the exception that it had a shared-wall integrated toilet. This model was used to test several hypotheses in addition to testing the daylight distribution: that the furniture in the model would have little effect on the results of the test, and that the daylight distribution on the walls would not be unusual. Also, in order to get a better understanding of how the daylight distribution on the floor was affected by the walls, four separate tests were run on this model:
 - **Test A** – Standard floor daylight test, with sensors on a centralized grid
 - **Test B** – Floor daylight test, with sensors on the room perimeter, adjacent to walls
 - **Test C** – Sensors on a centralized grid with scale model furniture items (bed, overbed table, bedside table, couch, chair, dresser and bedside stand).
 - **Test D** – Sensors embedded in walls at equivalent 48" and 66" heights.

Since the results of these tests indicated that the furniture had little effect on the floor daylight distribution, no furniture was used in any of the other tests. Also, since the distribution of light on the walls appeared to be as expected, no wall testing would be done for other tests. The glare constant from the daylight window was 143.

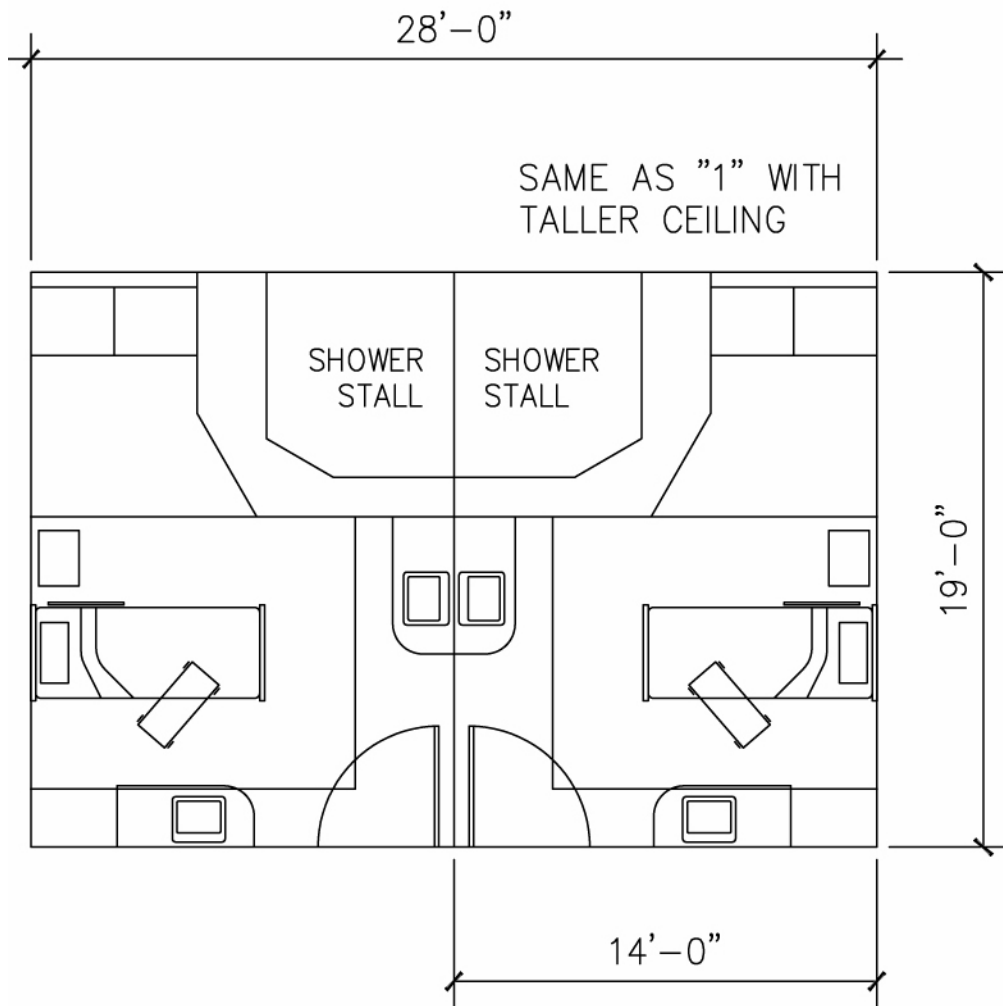


ZGF Hospital Daylight Testing - Test 4

rank = 26

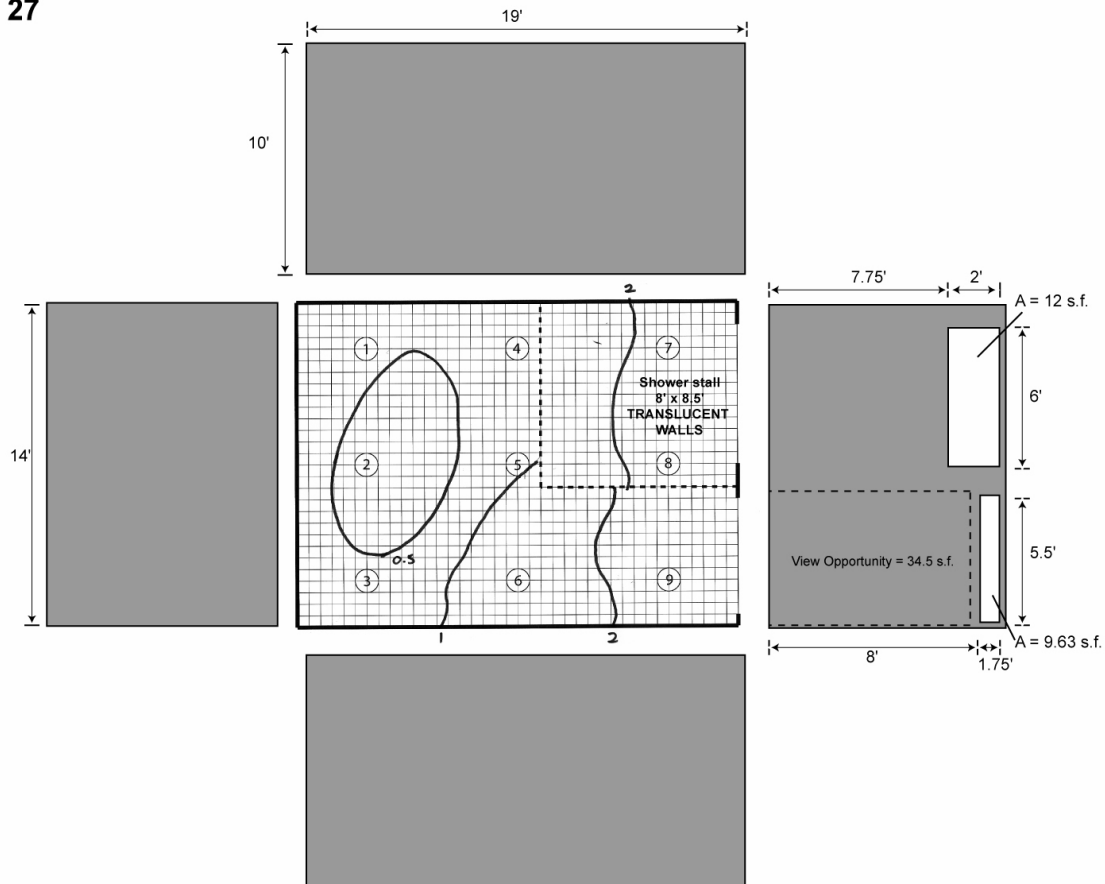


- Model 4** – This model was similar to previous designs, measuring 14' in width by 19' in length. The room had a flat ceiling of 10 feet. This higher ceiling height was to allow the top of a shortened toilet room to act as a light shelf. The toilet was an outboard shower stall room 7' high, allowing for 3' of space to reflect light into the back of the room. There are two windows incorporated in the test: the daylight window with a sill height of 8' (area = 9.63 s.f.) and a window over the toilet room with a sill height of 7'9" (12 s.f. - see Appendix C for room dimension details). The view opportunity was considered to be the area under the daylight window only, and had an area of 34.5 s.f. The glare constant from the daylight window (not including the toilet room window) was 133.



ZGF Hospital Daylight Testing - Test 5

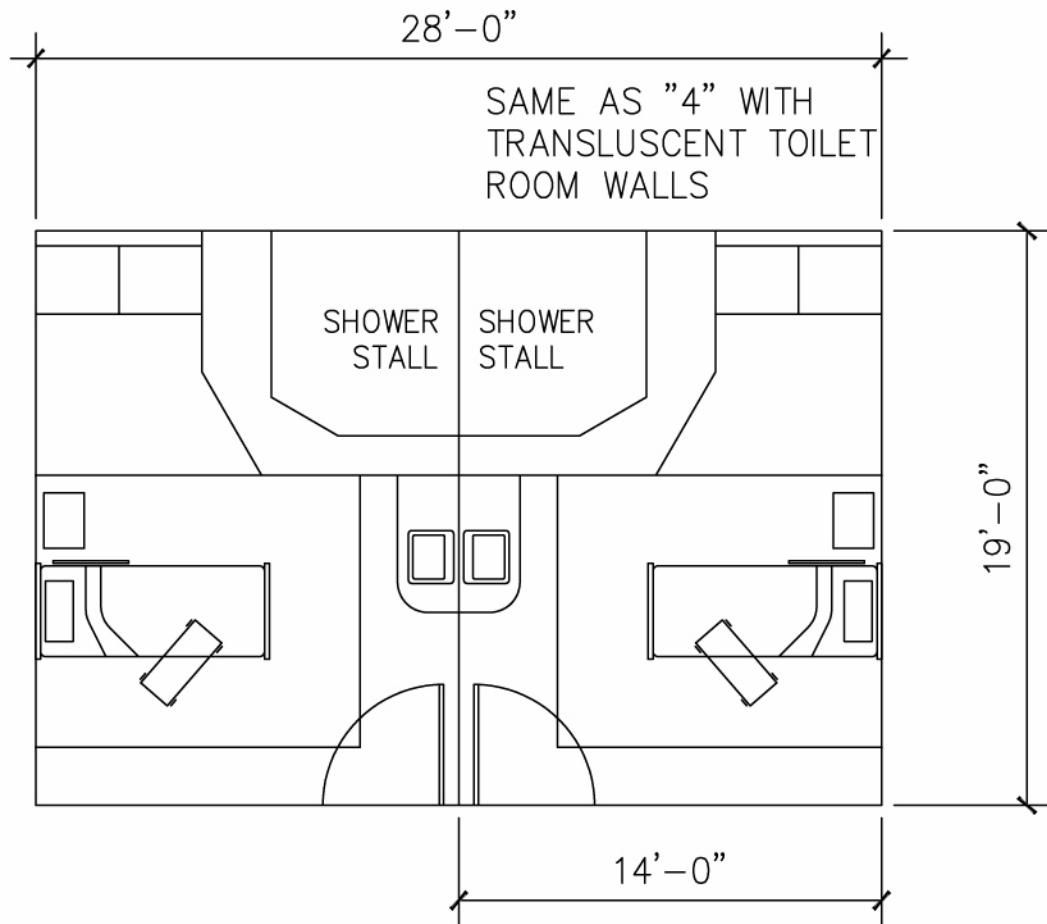
rank = 27



- Model 5** – This model was identical to Model 4, with the exception that the toilet room extended the entire way to the ceiling and had walls of textured glass to allow light to pass through the outboard toilet room while maintaining patient privacy. The window that was located above the toilet room in the previous model was now inside the toilet room. The toilet room was configured so that all of the plumbing and services could be placed along the wall, allowing for the full height of the toilet room walls to be unobstructed. In order to test for the effects of the translucent toilet walls, both the toilet room window and the main room daylight window were used in the testing. No actual translucent material was used in the model testing; the toilet room walls were removed and three tests were run on the model with different windows being unblocked:
 - Test 1** – Both windows unblocked
 - Test 2** – Toilet room window only unblocked
 - Test 3** – Daylight window only unblocked

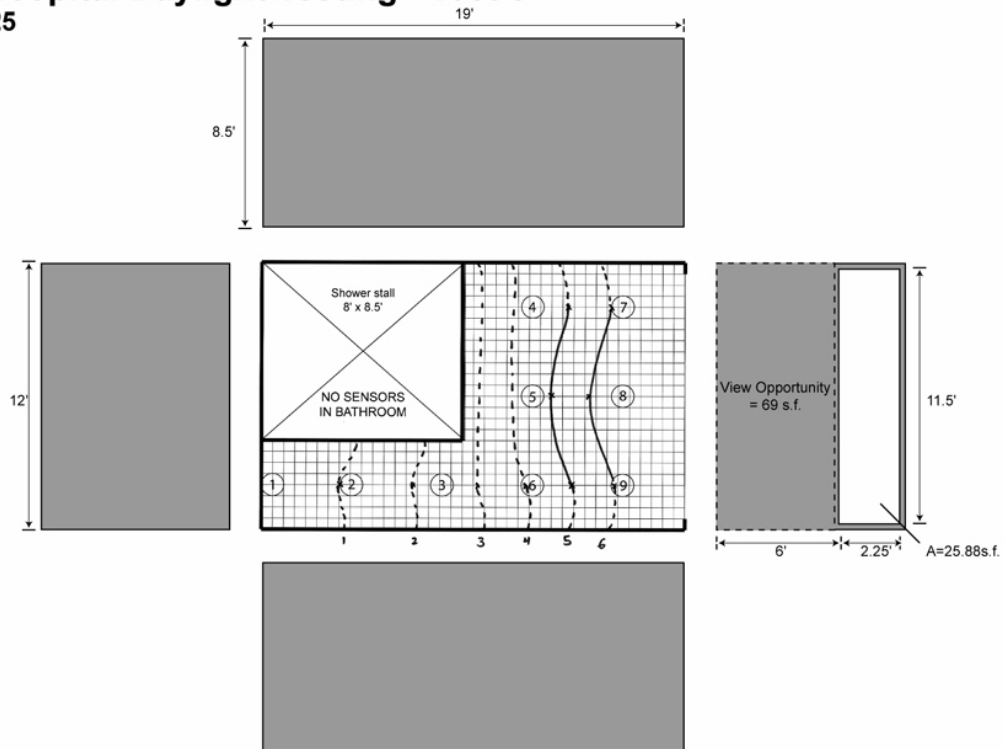
Calculations were performed after the testing to account for the effects of the glass toilet walls that interpolated the results of the three tests. The walls of the toilet room were

assumed to consist of corduroy glass with a transmissivity of 75%. The glare constant from the daylight window (not including the toilet room window) was 133.

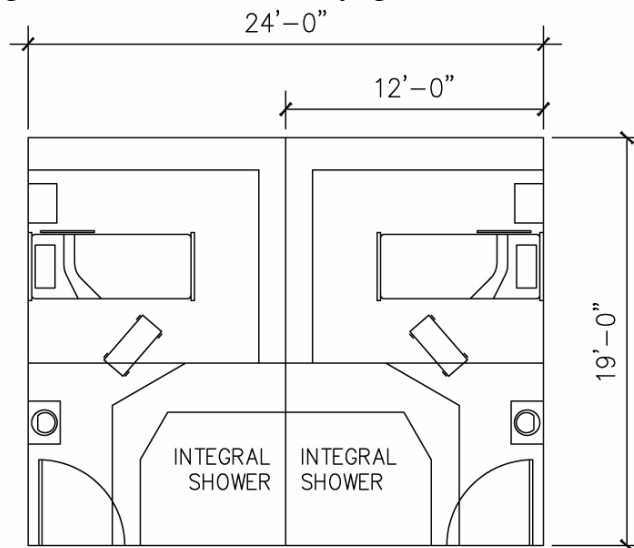


ZGF Hospital Daylight Testing - Test 6

rank = 25

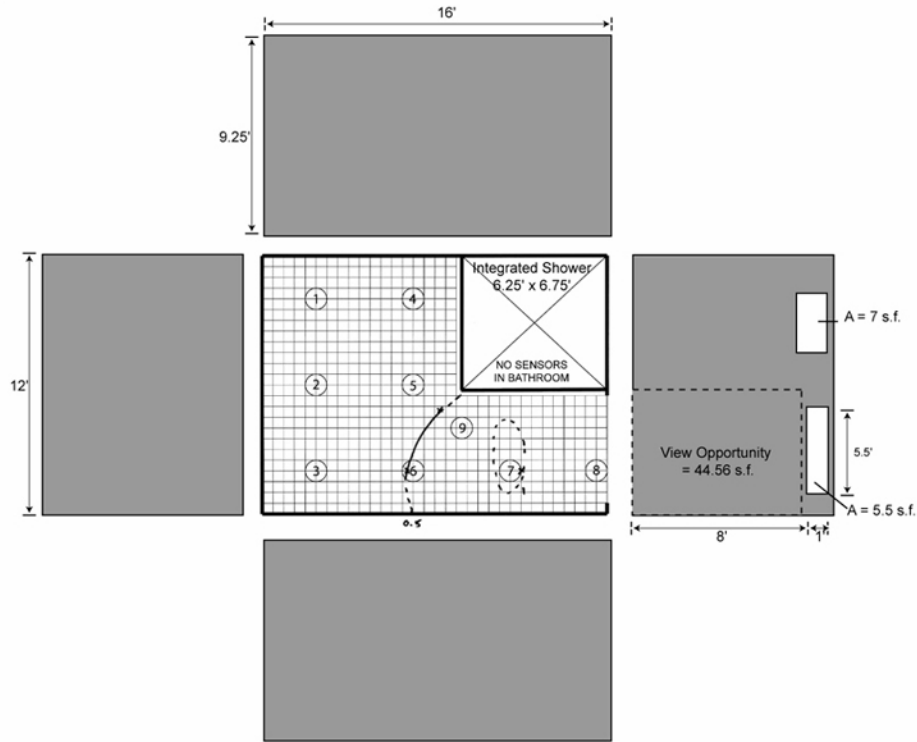


- Model 6** – This model had a width of 12' and a depth of 19', with a flat ceiling at 8.5'. The daylight window had a sill height of 6', with a glazing area of 25.88 s.f. and a view opportunity of 69 s.f. The model was tested with an inboard shower stall toilet, although an integral shower toilet room (shown below) would be required to allow for necessary clearances. The glare constant from the daylight window was 145.

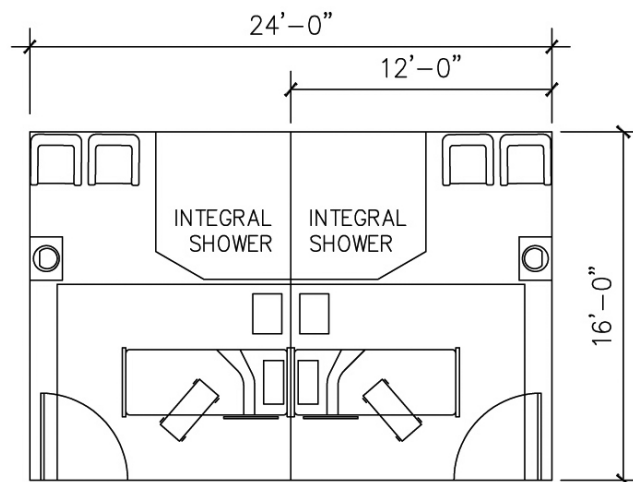


ZGF Hospital Daylight Testing - Test 7

rank = 28

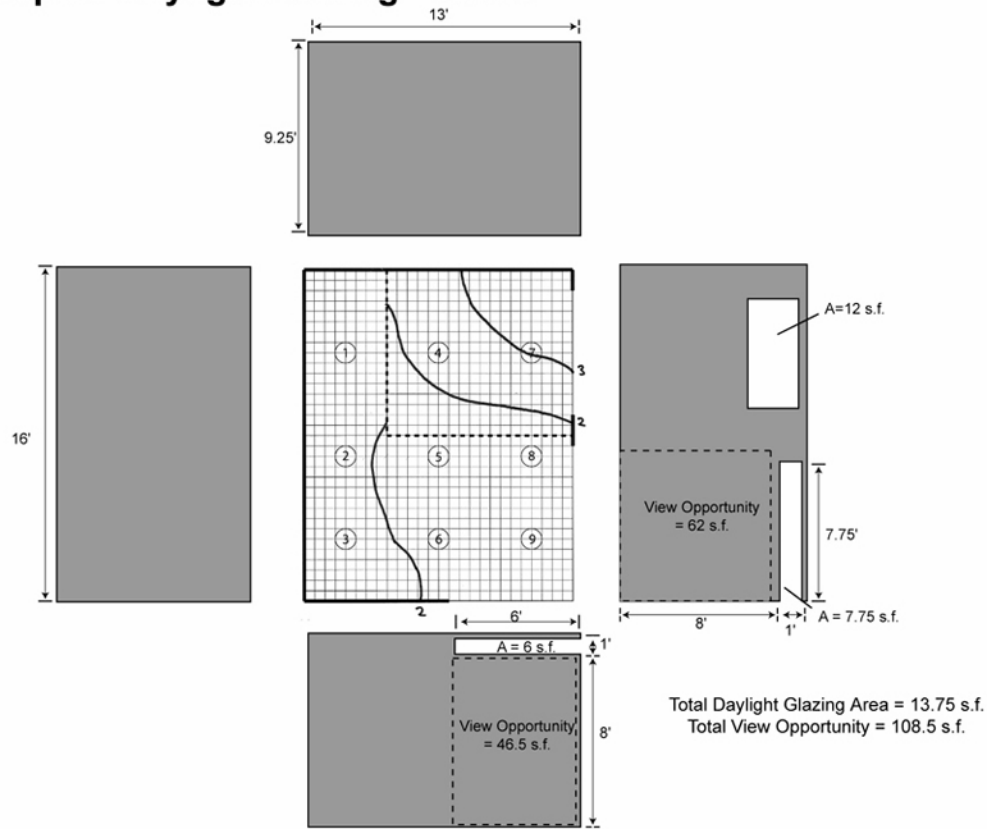


- Model 7** – This model represented a compact room configuration, with a width of 12', a depth of 16', and ceiling height of 9.25'. The sill height of the daylight window was 8', with a glazing area of 5.5 s.f and a view opportunity of 44.56 s.f. The toilet was an outboard integrated shower room. The glare constant from the daylight window was 80.



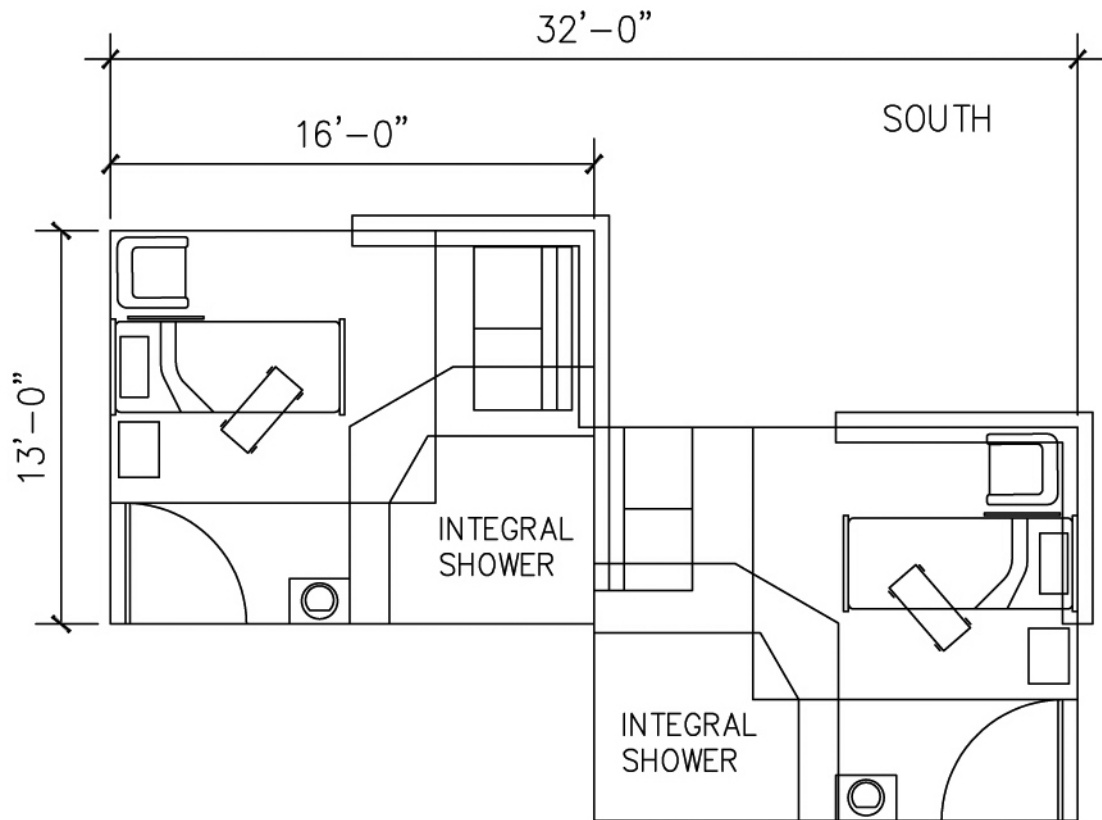
ZGF Hospital Daylight Testing - Test 8

rank = 4



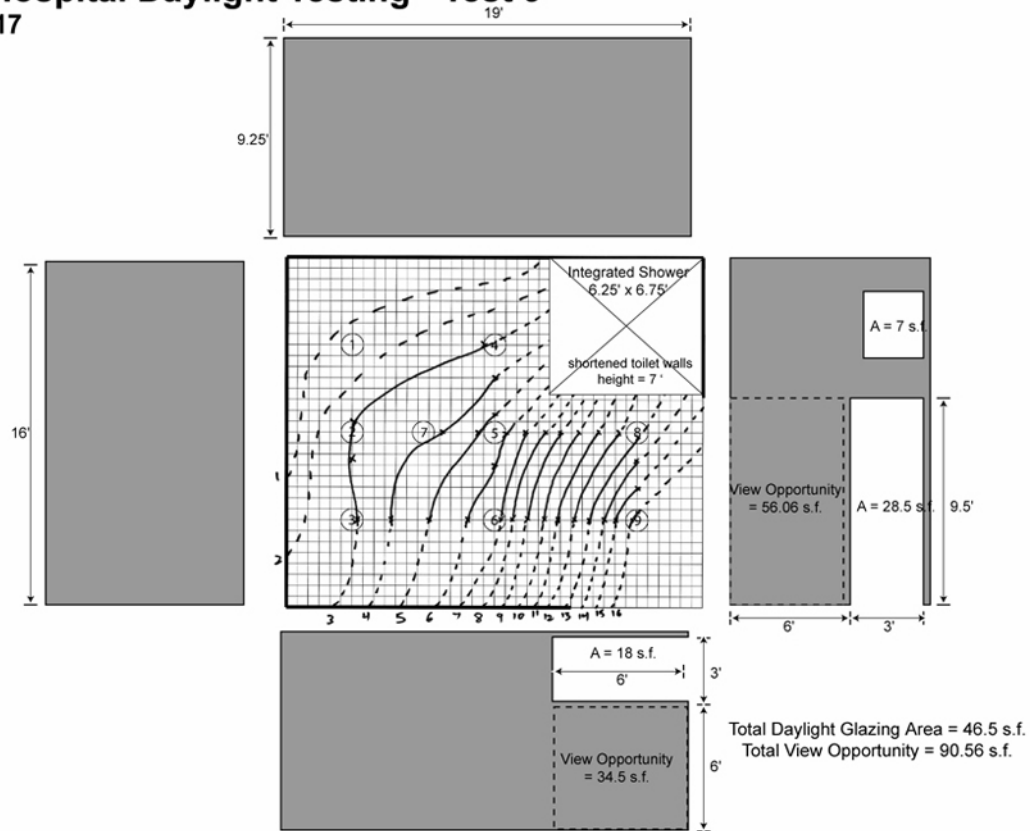
- Model 8** – This model represented a wide, shallow room, with a width of 16', a depth of 13' and a height of 9.25'. This model also had a corner window configuration: the daylight window wrapped around the southeast corner of the room and extended 6' along the east end of the south wall. This window had a sill height of 8' and a total glazing area of 13.75 s.f. The view opportunity area of 108.5 s.f. includes the area underneath the segment of the daylight window in the south wall. As with Model 5, this room had a similar outboard shower stall toilet room with translucent walls. The toilet room window had a sill height of 7' and a glazing area of 12 s.f. As with Model 5, three tests were performed in order to be able to calculate the effects of the translucent toilet room walls:
 - **Test 1** – Both windows unblocked
 - **Test 2** – Toilet room window only unblocked
 - **Test 3** – Daylight window only unblocked

As with Model 5, calculations were performed after the test to account for the effects of the translucent toilet walls. The glass used for the toilet room walls was assumed to be the same as in Model 4. The model was tested with an shower stall room toilet, although an integral shower toilet room (shown below) would be required to allow for necessary clearances. The glare constant from the daylight window (not including the toilet room window) was 136.

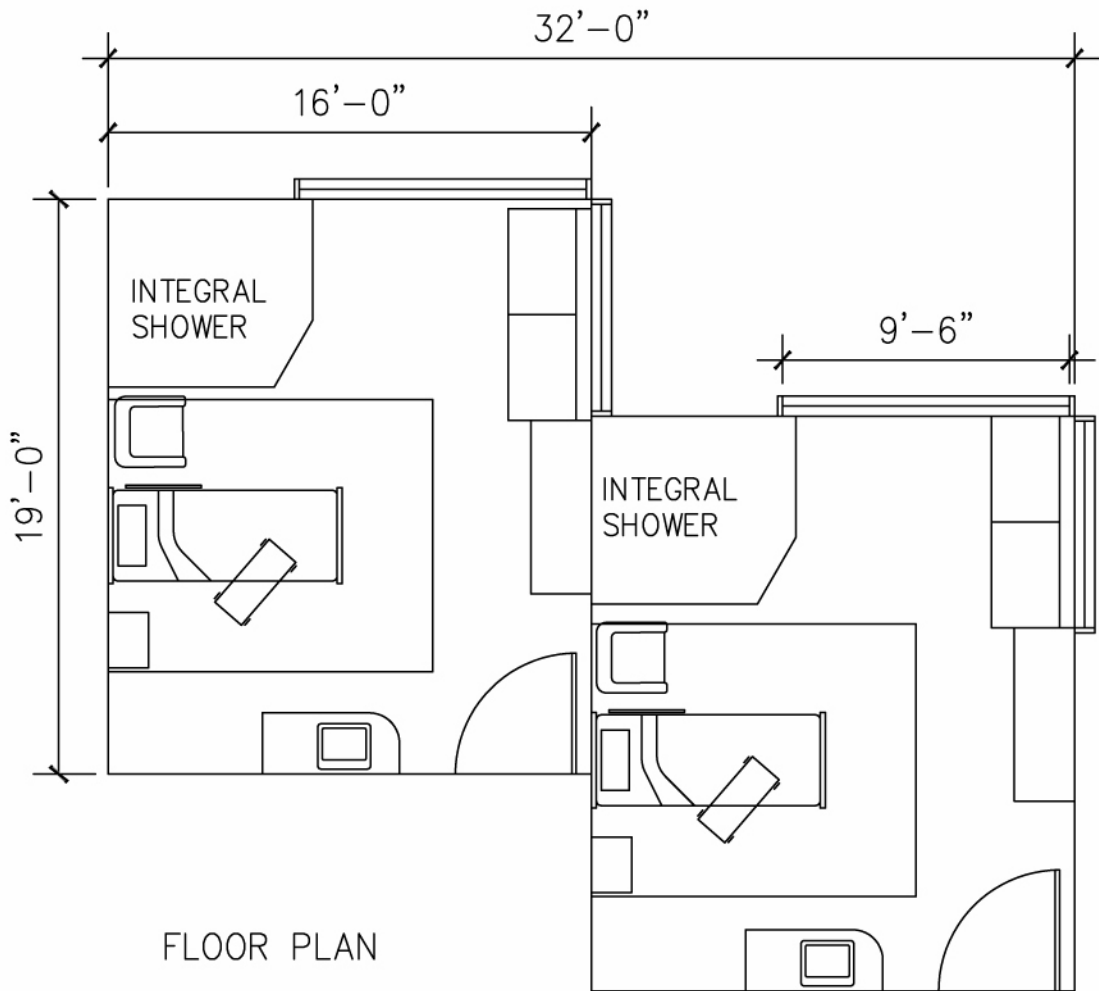


ZGF Hospital Daylight Testing - Test 9

rank = 17

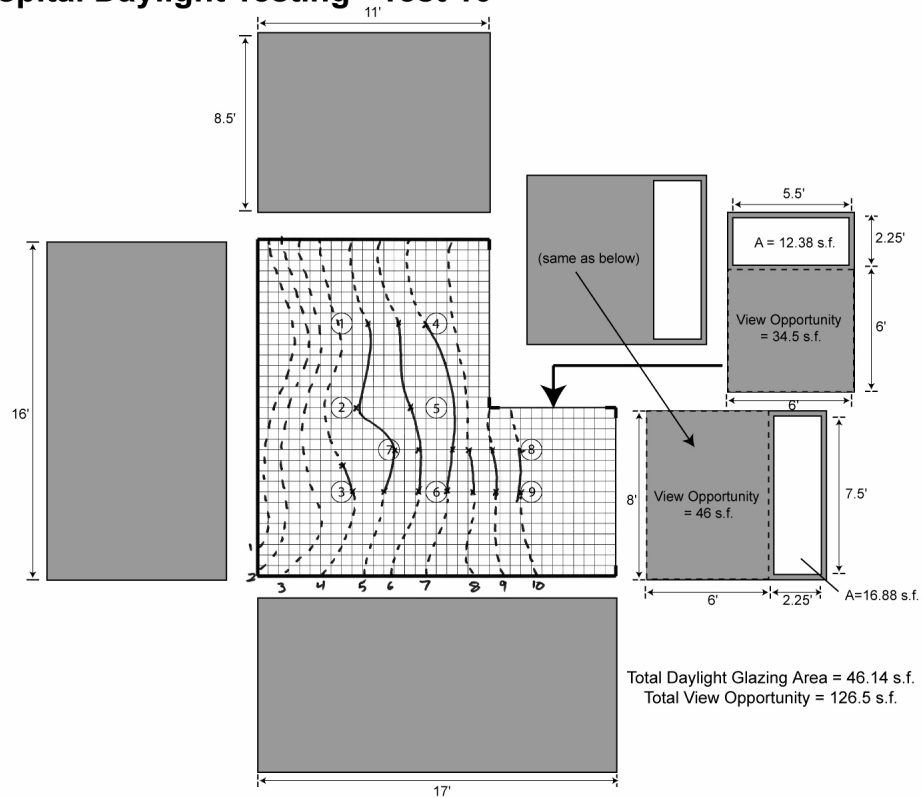


- Model 9** – This configuration was similar to that of Model 4 in that it had an outboard toilet with shortened walls so that the top of the toilet room could act as a light shelf. The room had a width of 16', a depth of 19', and a height of 9.25'. As with Model 8, this room had a corner daylight window that extended 6' down the south wall, although the sill height for this model was 6'. The daylight glazing area was 46.5 s.f. with a view opportunity of 90.56 s.f. The toilet was an outboard integrated shower room that was 7' high. The window over the toilet room had a sill height of 7' and a glazing area of 7 s.f. The glare constant from the daylight window (not including the toilet room window) was 146.

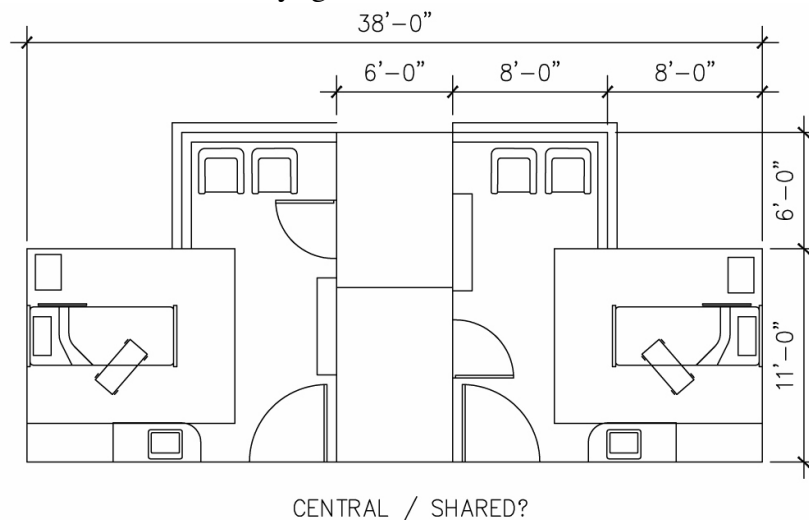


ZGF Hospital Daylight Testing - Test 10

rank = 16

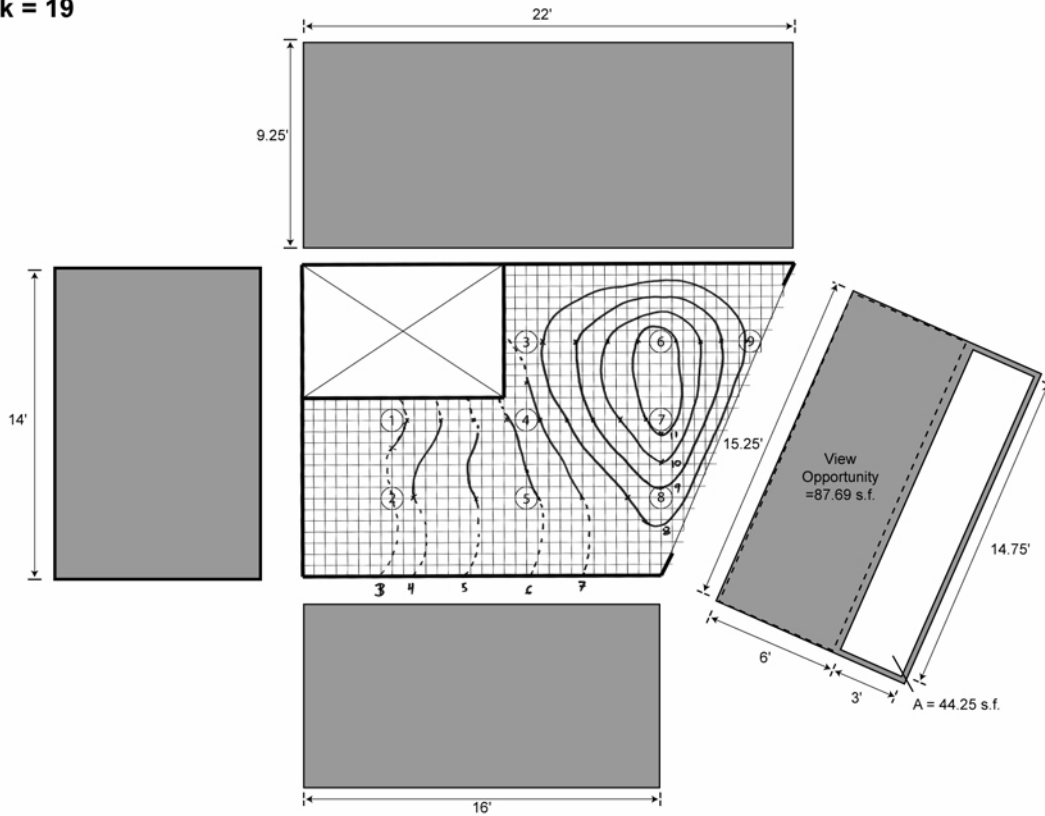


- Model 10** – This model had a notched outer wall with a floor area equivalent to a rectangular room with a width of 16' and a depth of 14'. The ceiling height was 8.5'. This model was assumed to have a shared-wall integrated shower room. The daylight window had a sill height of 6', a glazing area of 46.14 s.f., and a view opportunity of 126.5 s.f. The glare constant from the daylight windows was 139.

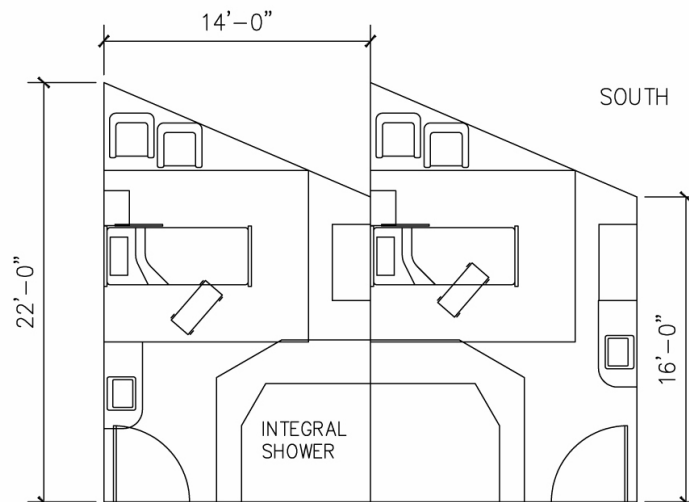


ZGF Hospital Daylight Testing - Test 11

rank = 19

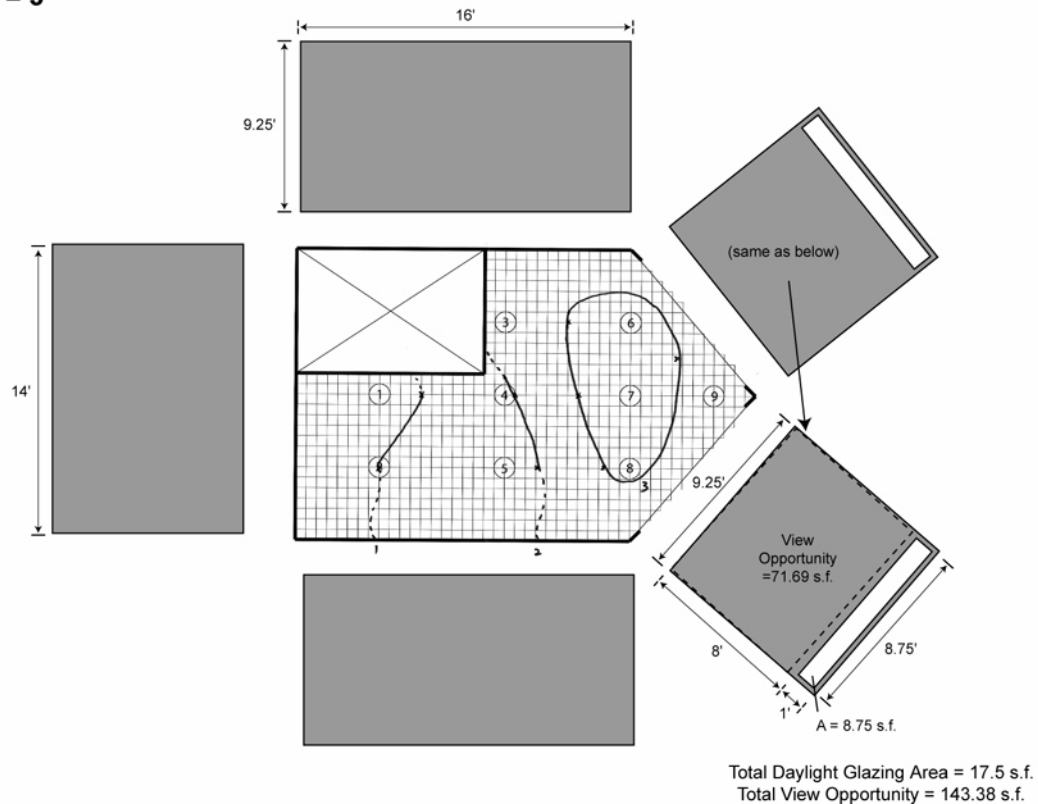


- Model 11** – This model had a slanted outer wall with a floor area equivalent to a rectangular room with a width of 14' and a depth of 19'. The ceiling height was 9.25'. The daylight window had a sill height of 6', with a glazing area of 44.25 s.f. and a view opportunity of 87.69 s.f. The toilet was an inboard shower stall room. The glare constant from the daylight window was 162.

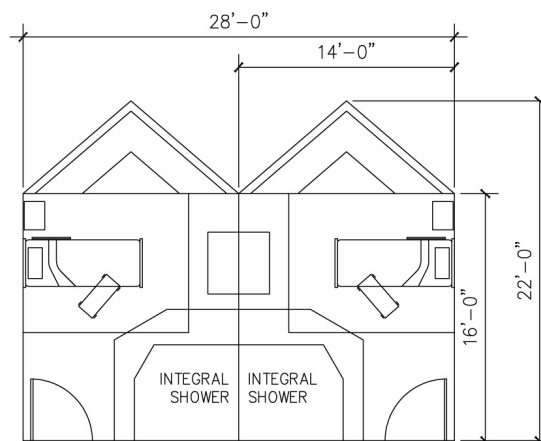


ZGF Hospital Daylight Testing - Test 12

rank = 3

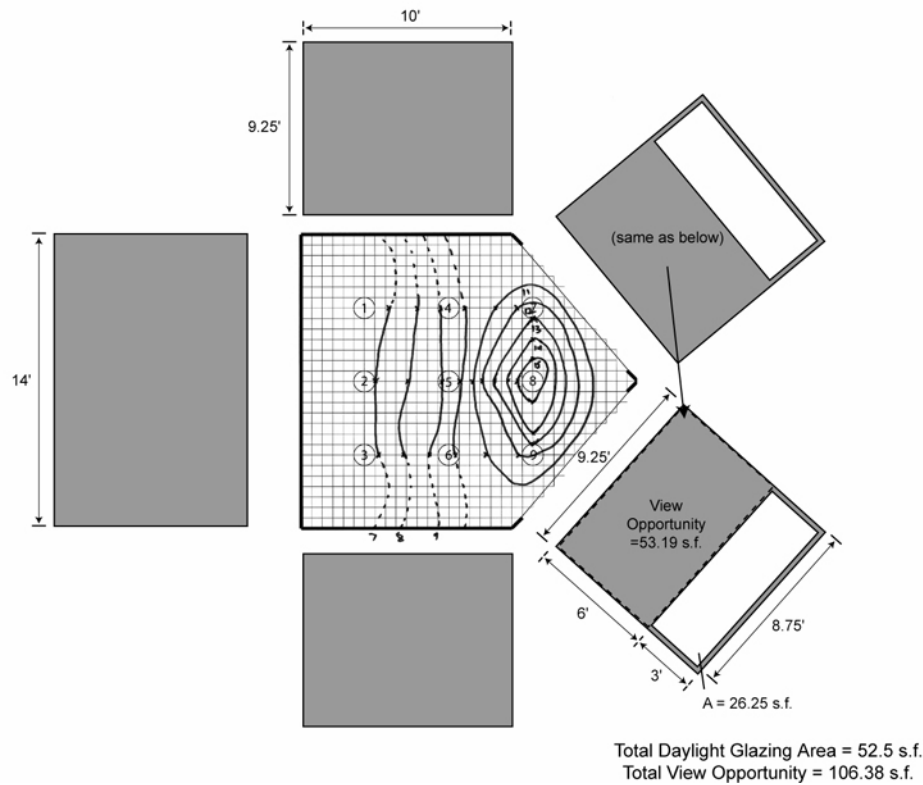


- Model 12** – This model had a pointed outer wall with a floor area equivalent to a rectangular room with a width of 14' and a depth of 19'. The ceiling height was 9.25'. The daylight window had a sill height of 8', with a glazing area of 17.5 s.f. and a view opportunity of 143.38 s.f. The model was tested with an inboard shower stall toilet, although an integral shower toilet room (shown below) would be required to allow for necessary clearances. The glare constant from the daylight windows was 130.

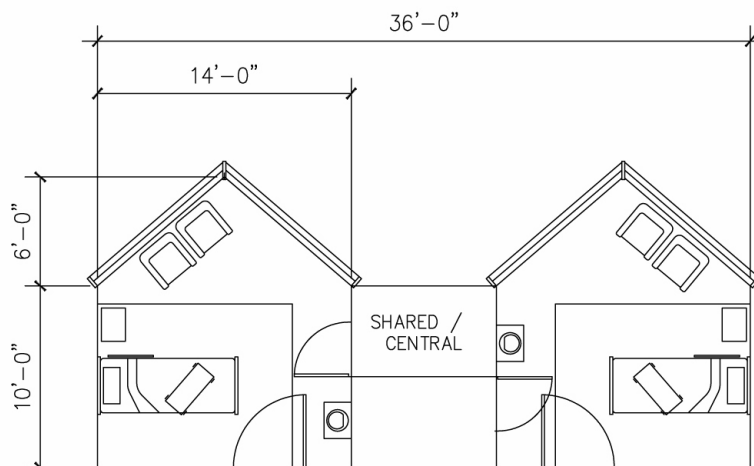


ZGF Hospital Daylight Testing - Test 13

rank = 22

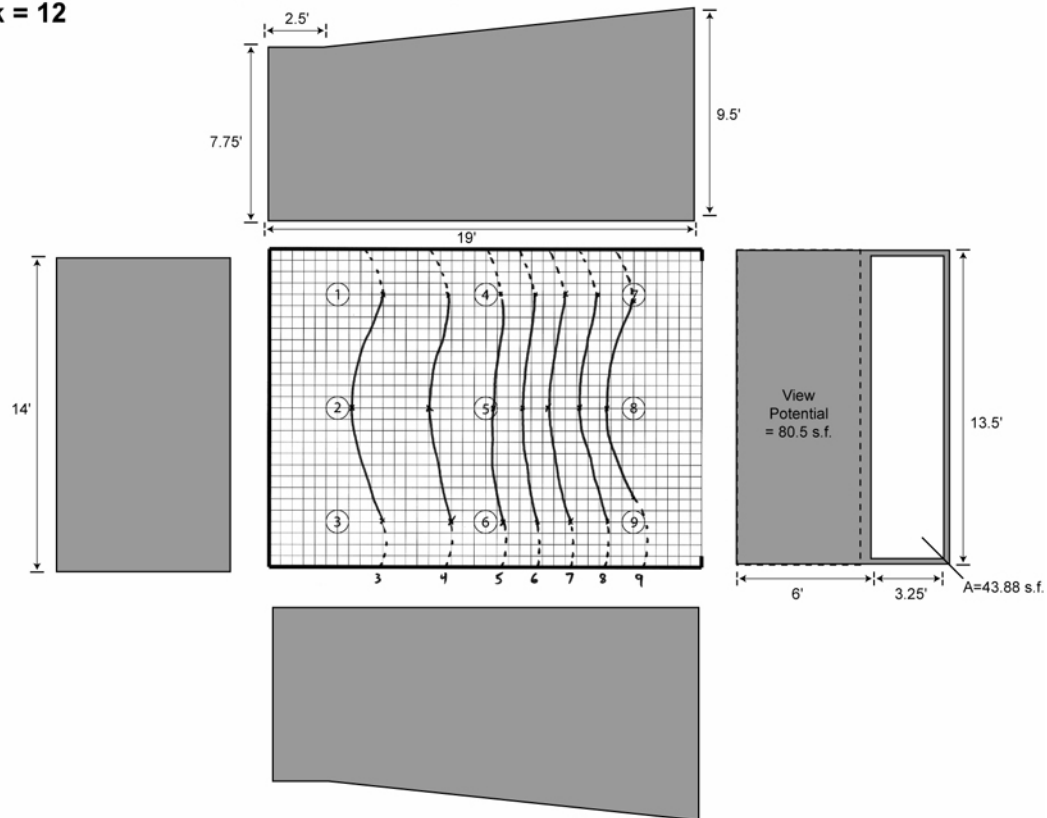


- Model 13** – This configuration represented a compact design with discrete zoning possibilities. The room had a pointed outer wall with a floor area equivalent to a rectangular room with a width of 14' and a depth of 13'. The ceiling height was 9.25'. The daylight window had a sill height of 6', with a glazing area of 52.5 s.f. and a view opportunity of 106.38 s.f. The toilet was assumed to be a shared-wall integrated shower room. The glare constant from the daylight windows was 196.

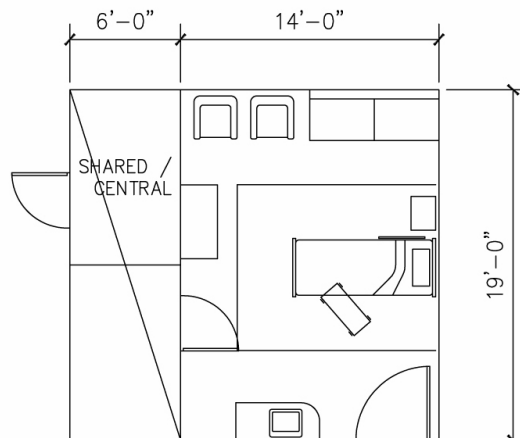


ZGF Hospital Daylight Testing - Test 14

rank = 12

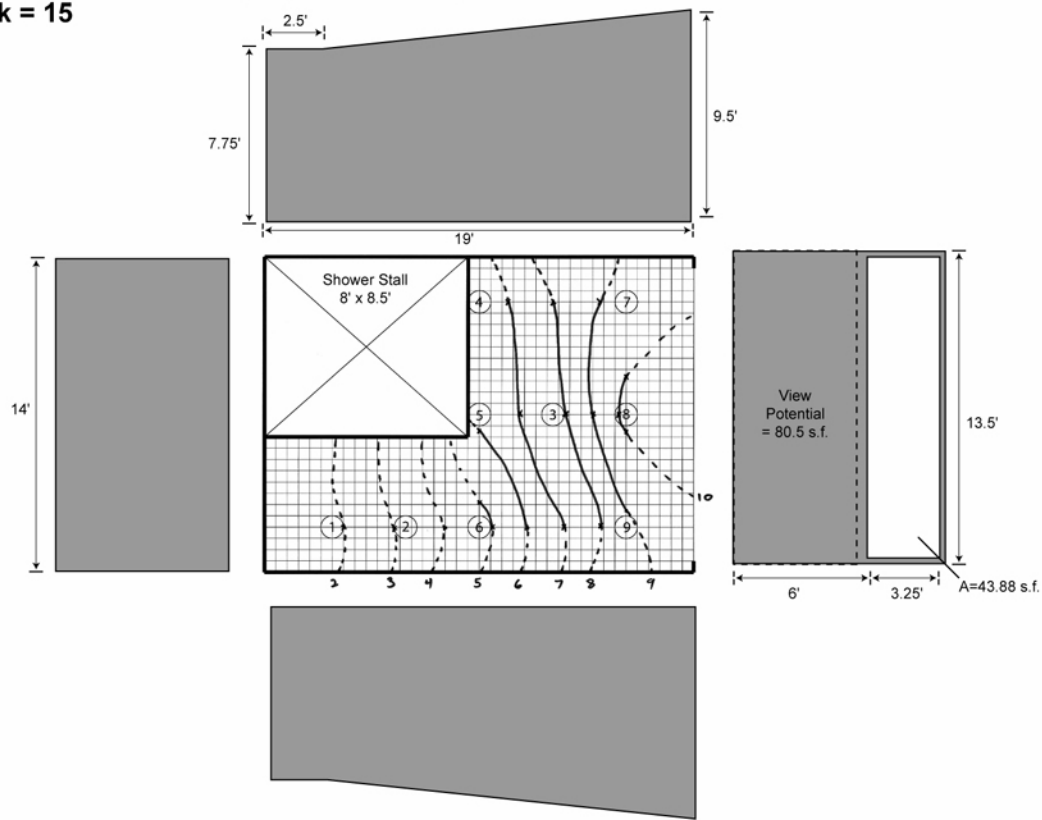


- Model 14** – This model had a slanted ceiling with a 7.75' height at the hallway and a 9.5' height at the outer wall. This configuration may require some of the HVAC services to be run external to the room. The room was 14' wide and 19' deep. The daylight window had a 6' sill, allowing for a 43.88 s.f. glazing area and a 80.5 s.f. view opportunity. The toilet was assumed to be a shared-wall integrated shower room. The glare constant from the daylight window was 143.

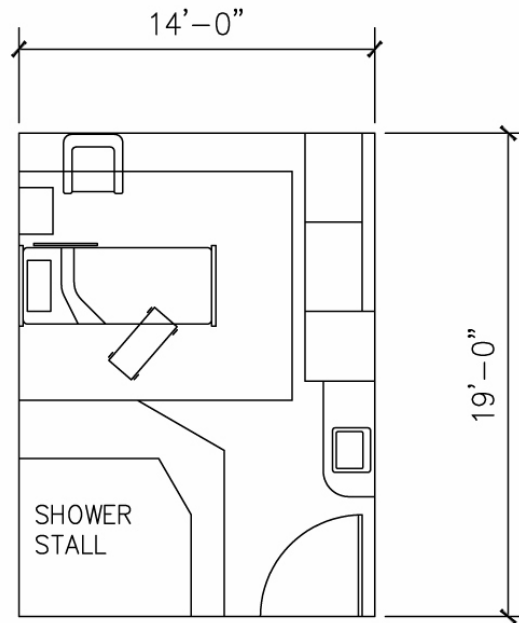


ZGF Hospital Daylight Testing - Test 15

rank = 15

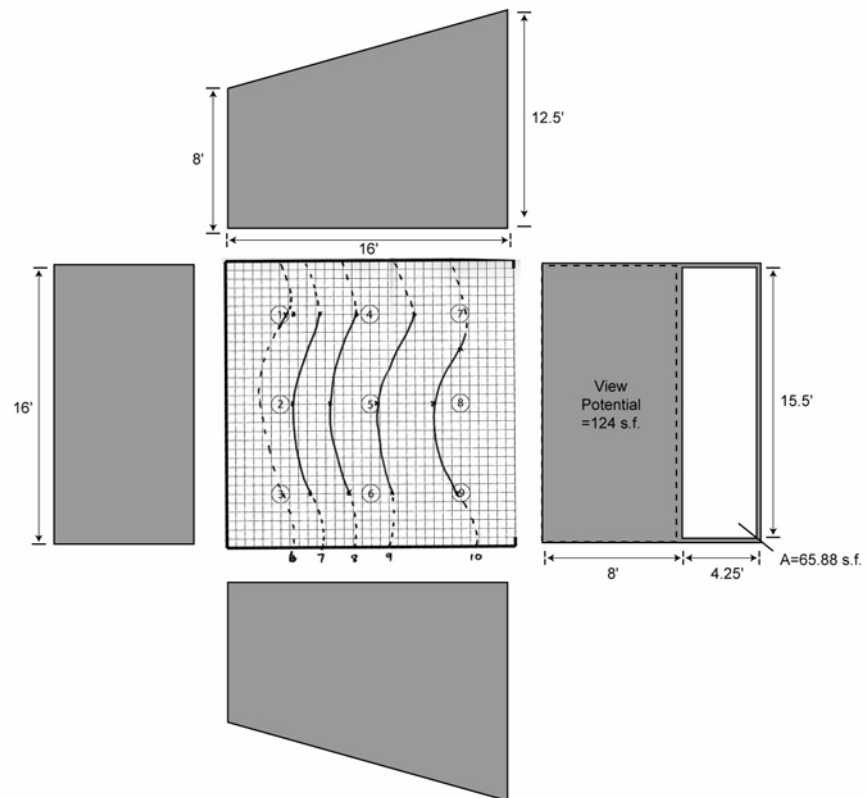


- Model 15** – This configuration was identical to that of Model 14, except that the toilet was an inboard shower stall room. The glare constant from the daylight window was 143.

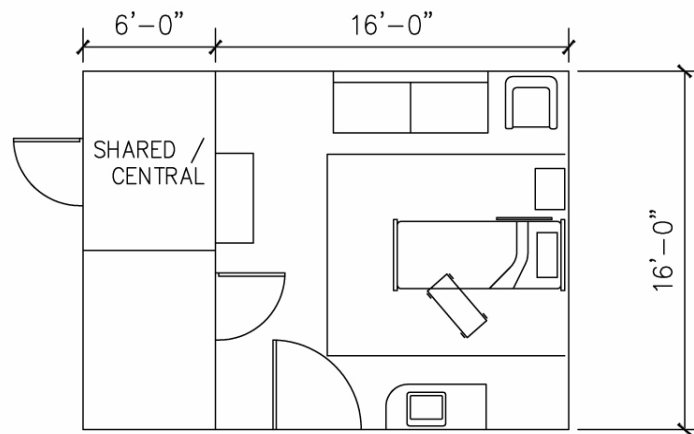


ZGF Hospital Daylight Testing - Test 16

rank = 8

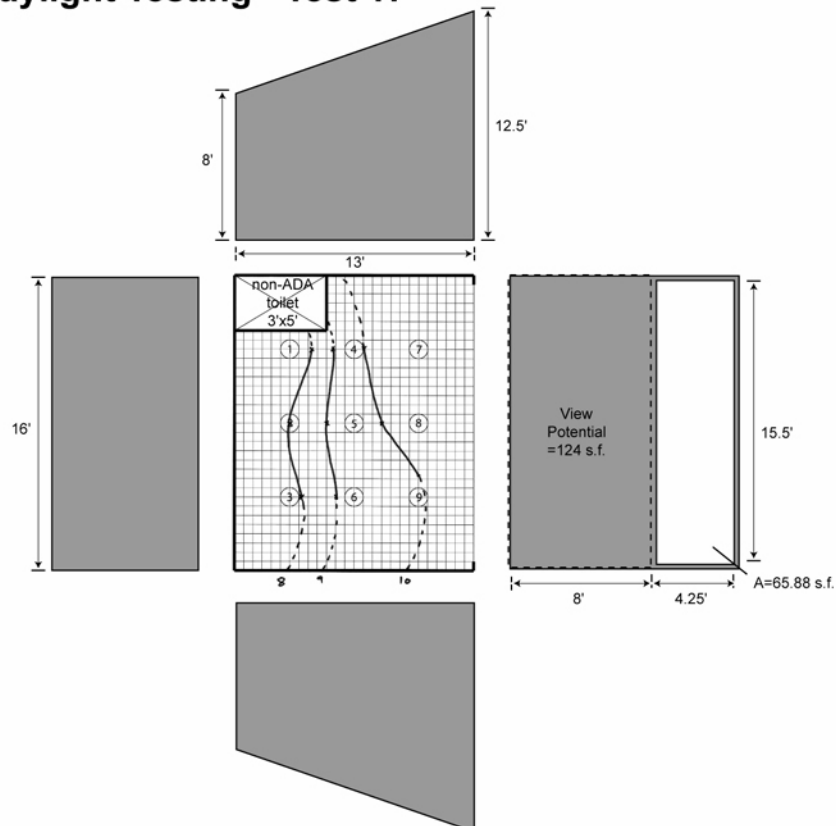


Model 16 – This model had a slanted ceiling with a height of 8' at the hallway and a height of 12.5' at the outer wall. The room had a width of 16' and a depth of 16'. The daylight window sill height was 8', with a glazing area of 65.88 s.f. and a view opportunity of 124 s.f. The toilet was assumed to be a shared-wall integrated shower room. The glare constant from the daylight window was 73.



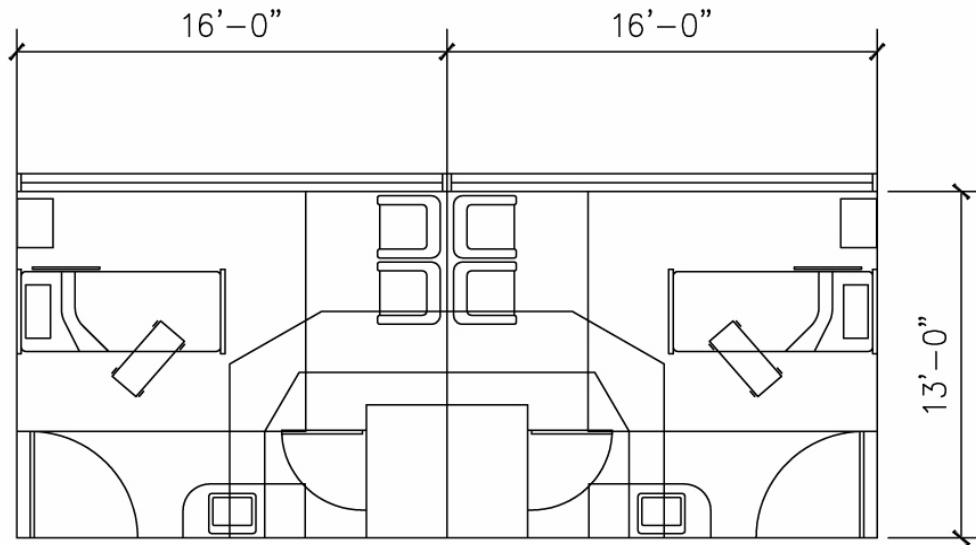
ZGF Hospital Daylight Testing - Test 17

rank = 7



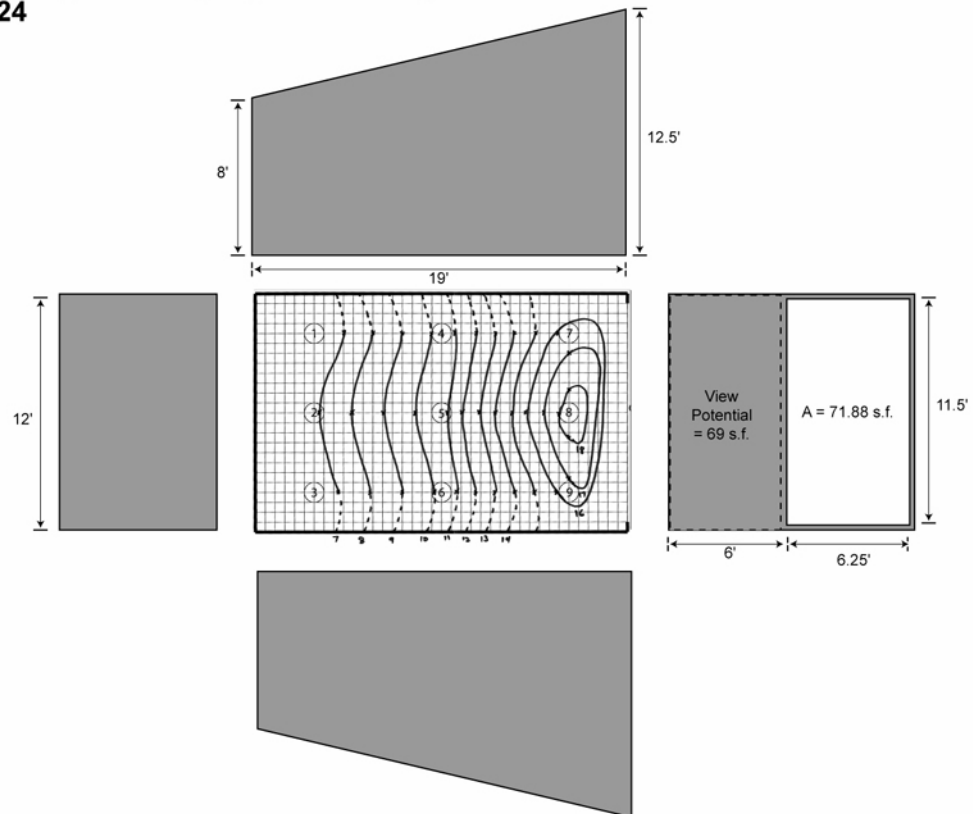
- **Model 17** – This configuration was essentially identical to that of Model 16, but with a 13' room depth. The model was tested with inboard minimal size toilet room, although an

integral shower toilet room (shown below) would be preferable. This design was thought to have the highest potential for daylighting. The glare constant from the daylight window was 68.

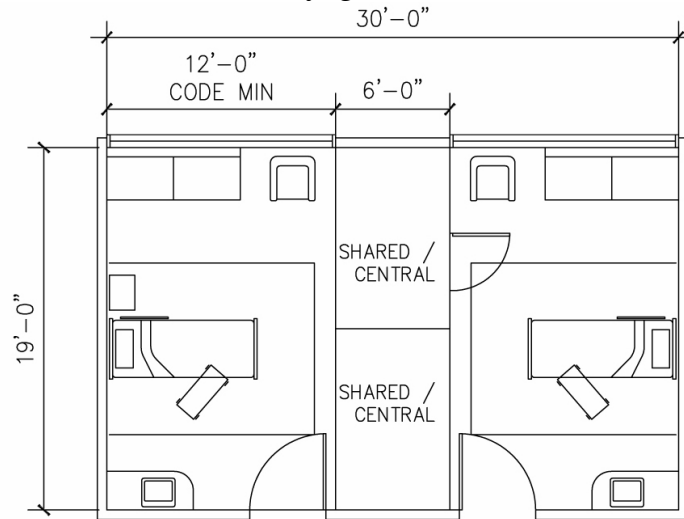


ZGF Hospital Daylight Testing - Test 18

rank = 24

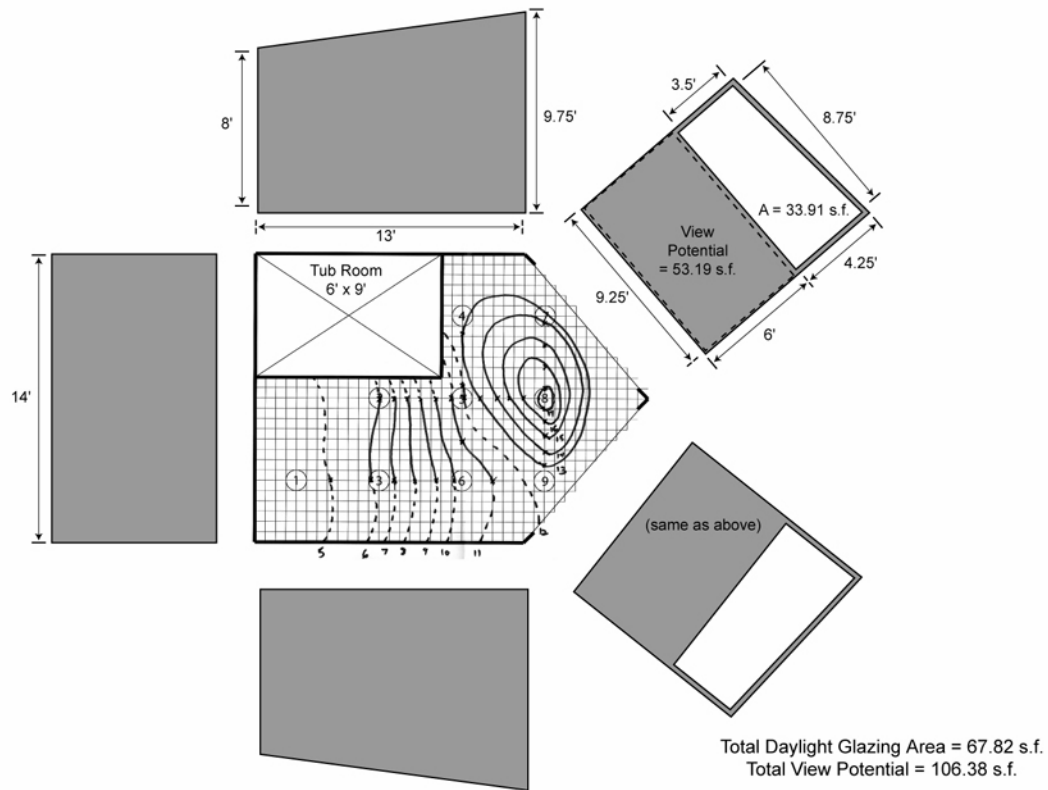


- Model 18** – This model had a slanted ceiling with a height of 8' at the hallway and a height of 12.5' at the outer wall. The room had a width of 12' and a depth of 19'. The daylight window had a sill height of 6', with a glazing area of 71.88 s.f. and a view opportunity of 124 s.f. The toilet was assumed to be a shared-wall integrated shower room. The glare constant from the daylight window was 95.



ZGF Hospital Daylight Testing - Test 19

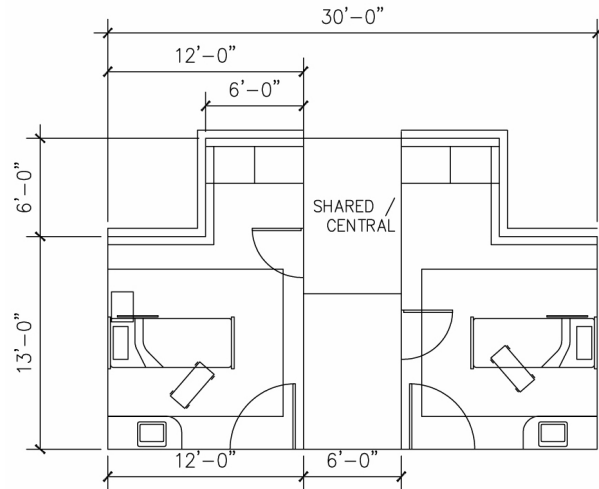
rank = 20



-
- 28'-0"
- 14'-0"
- CODE REQ. CLEARANCES?
- 6'-0"
- 13'-0"
- 19'-0"
- INTEGRAL SHOWER
- INTEGRAL SHOWER

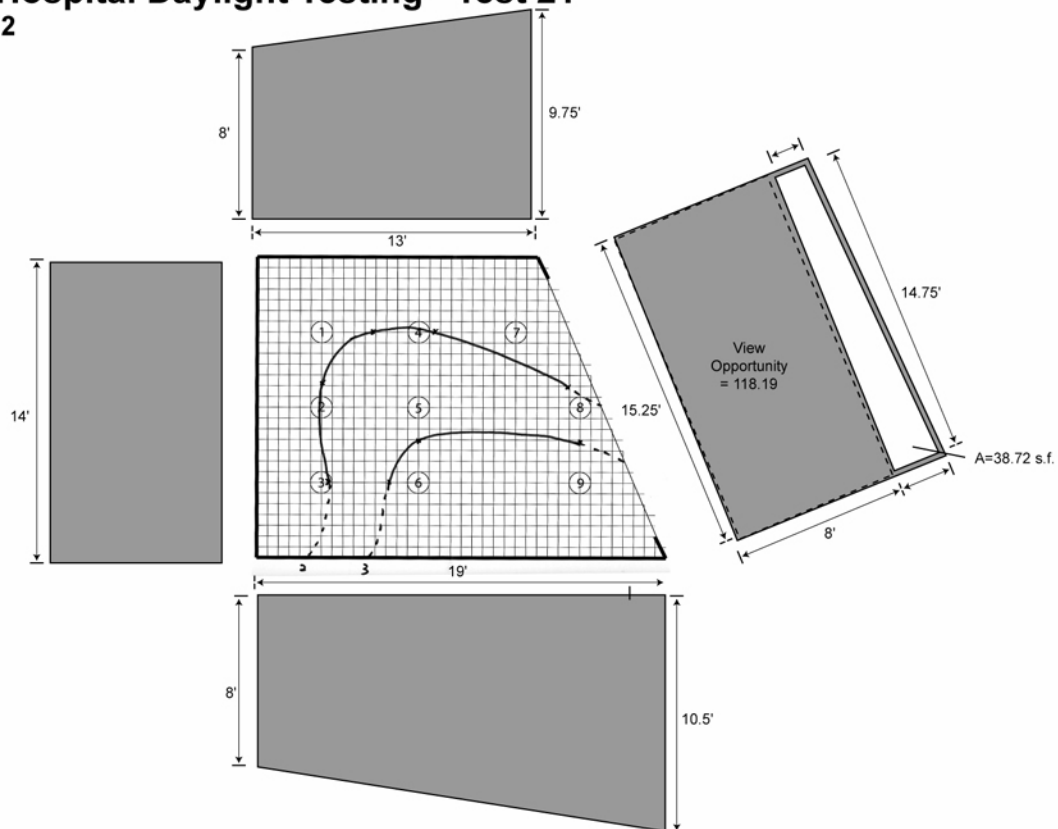
rank = 14

- Model 20** - This model had a slanted ceiling, with a height of 8' at the hallway and a height of 12.5' at the outer wall. The room had a notched outer wall with a floor area equivalent to a rectangular room with a width of 12' and a depth of 16'. The daylight window had a sill height of 8', with a glazing area of 57.76 s.f. and a view opportunity of 139.5 s.f. The toilet was assumed to be a shared-wall integrated shower room. The glare constant from the daylight windows was 73.

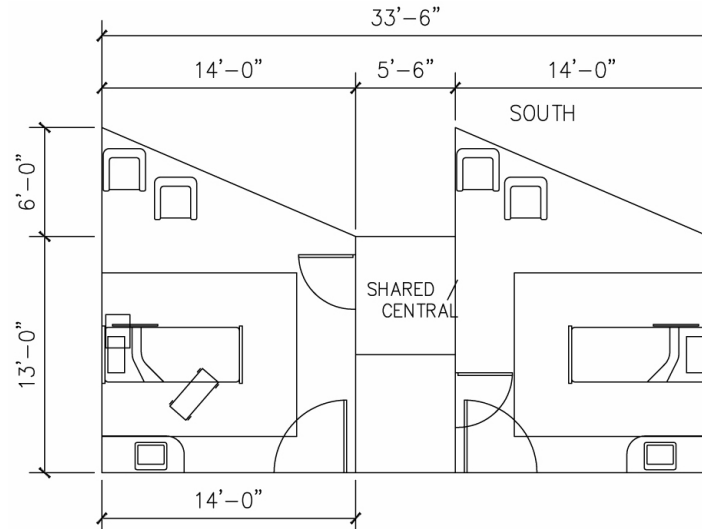


ZGF Hospital Daylight Testing - Test 21

rank = 2

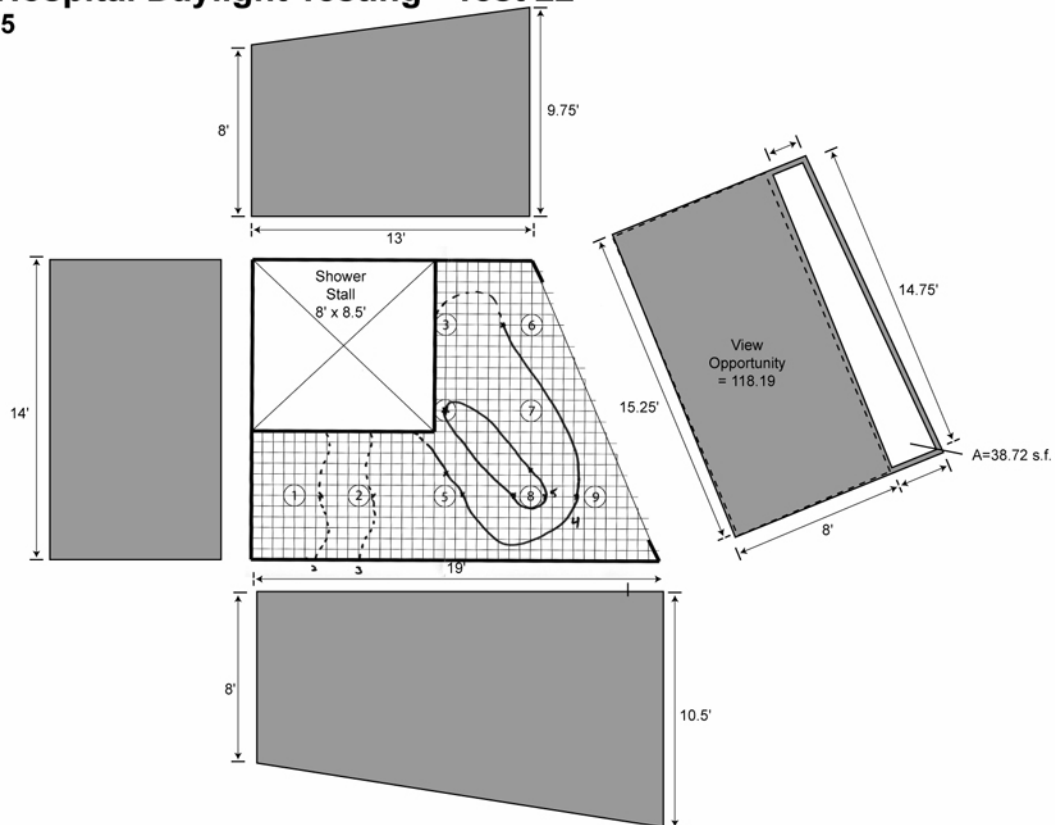


- Model 21** - This model had a slanted ceiling with a height of 8' at the hallway and a height of 10.5' at the outer wall. The room had a slanted outer wall with a floor area equivalent to a rectangular room with a width of 14' and a depth of 16'. The daylight window had a sill height of 8', with a glazing area of 38.72 s.f. and a view opportunity of 118.19 s.f. The toilet was assumed to be a shared-wall integrated shower room. The glare constant from the daylight window was 88.

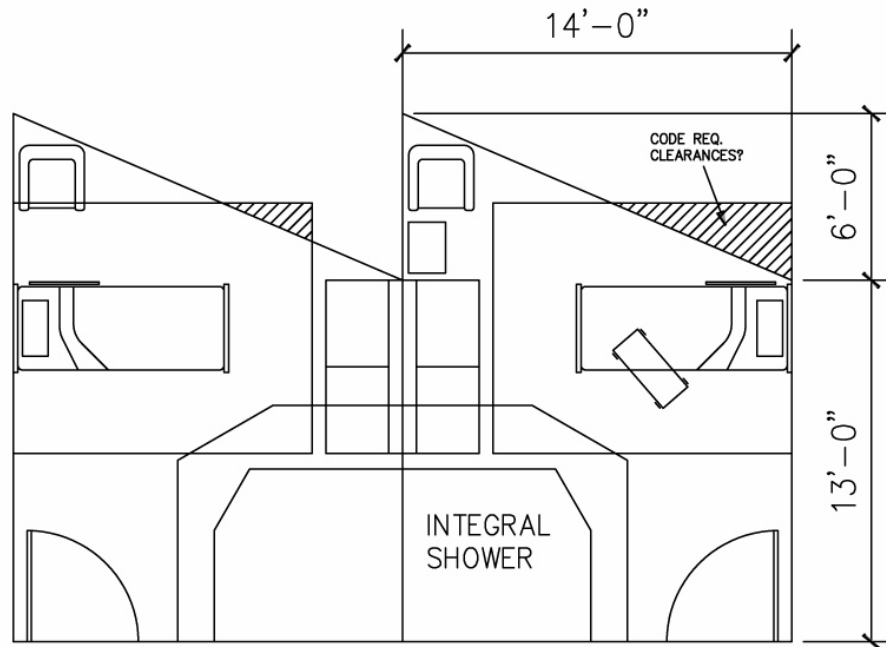


ZGF Hospital Daylight Testing - Test 22

rank = 5

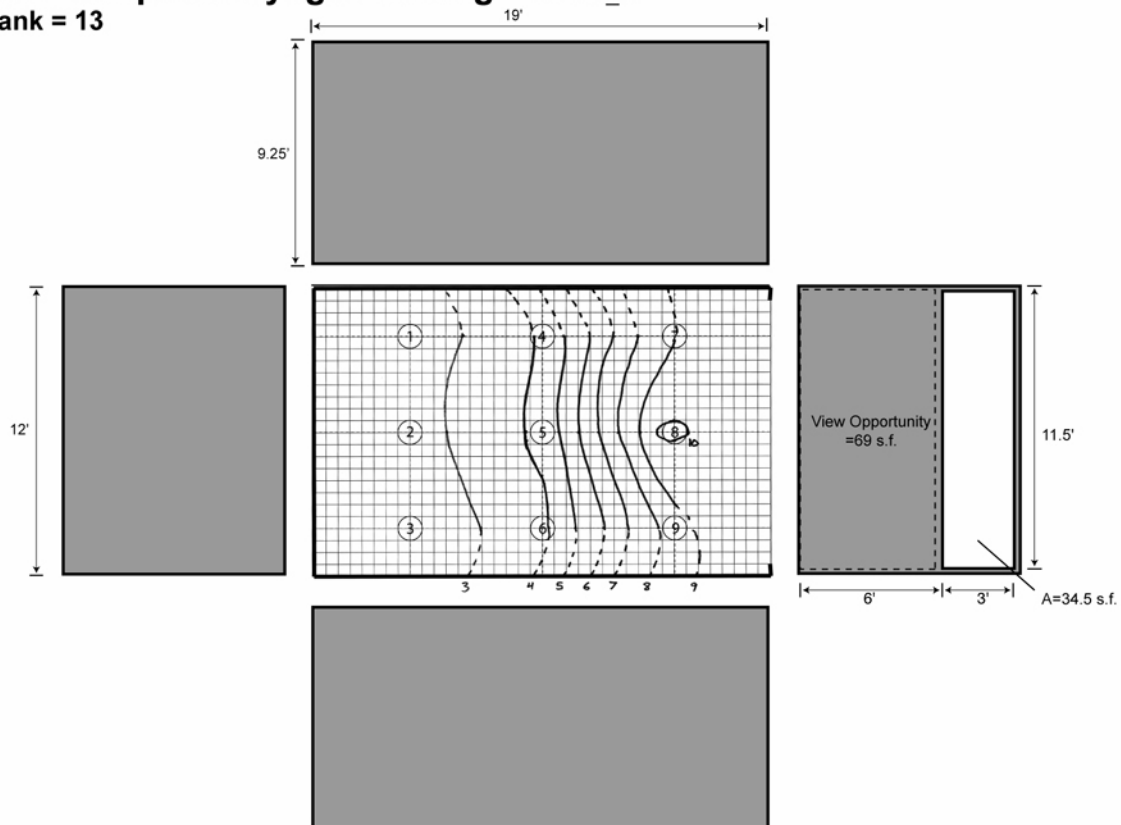


- **Model 22** - This configuration was identical to that of Model 21, but with an inboard shower stall toilet. The glare constant from the daylight window was 88.



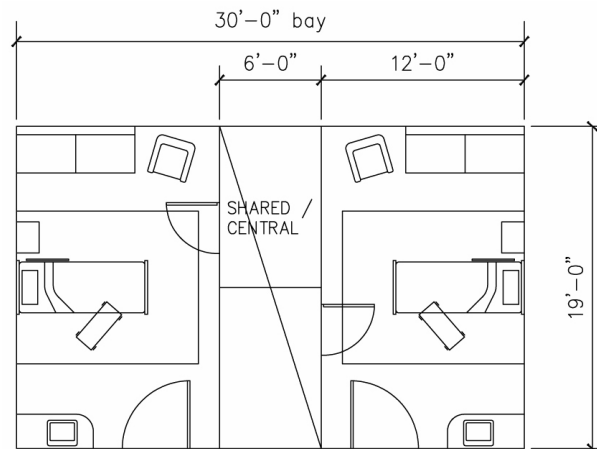
ZGF Hospital Daylight Testing - Test 23

rank = 13



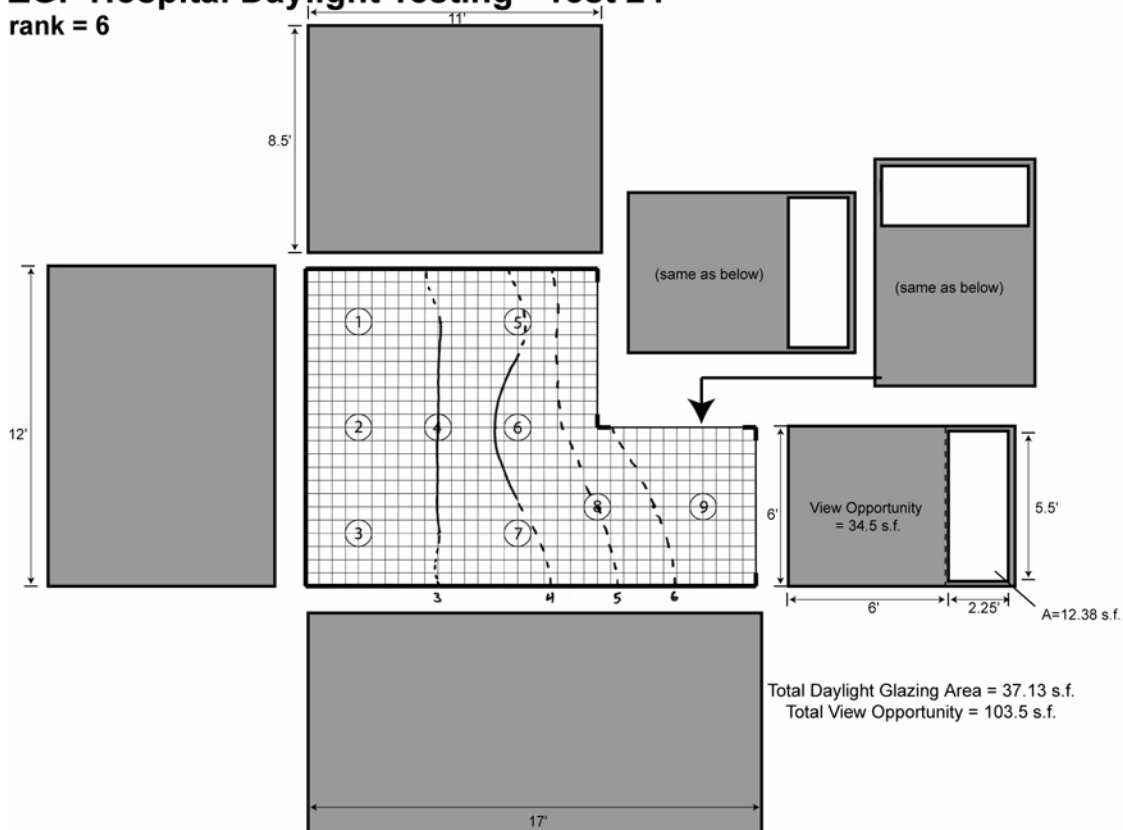
The first 22 models comprised the initial round of tests in November 2004. Based on the results of the initial testing and configuration limitations identified by ZGF, it was decided to retest some of the models with modified geometries. Most of these were altered to have narrower room widths in order to conform to typical bay size limitations.

- **Model 23** – This configuration was a modified version of Model 3 with a 12' width. The daylight window had a glazing area of 34.5 s.f. and a view opportunity of 69 s.f. The glare constant from the daylight window was 139.

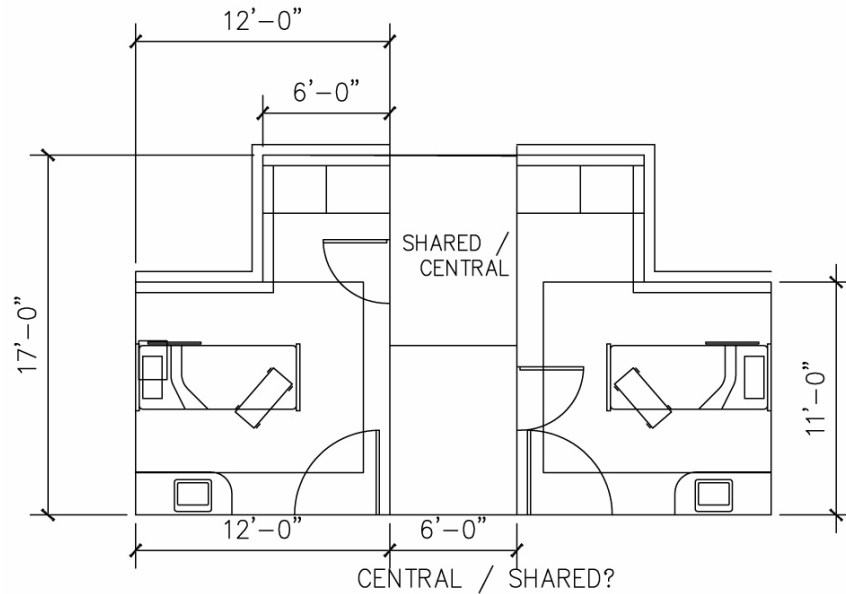


ZGF Hospital Daylight Testing - Test 24

rank = 6

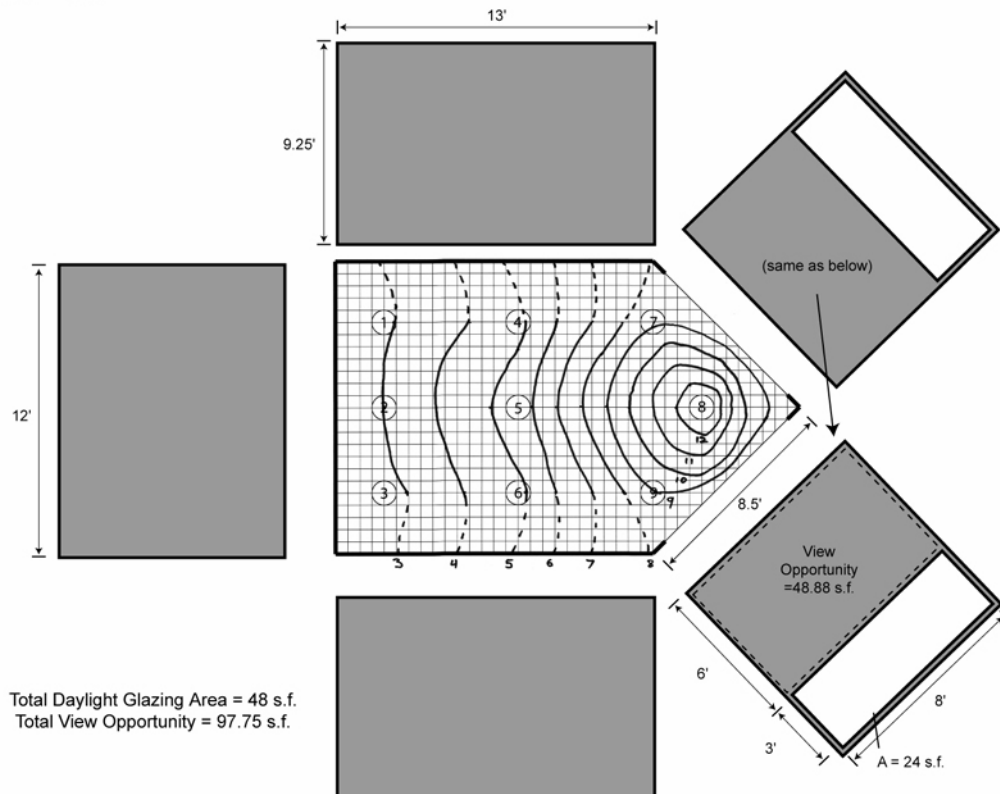


- Model 24** - This configuration was a modified version of Model 10 with a 12' width. The daylight window had a glazing area of 37.13 s.f. and a view opportunity of 103.5 s.f. The glare constant from the daylight window was 178.

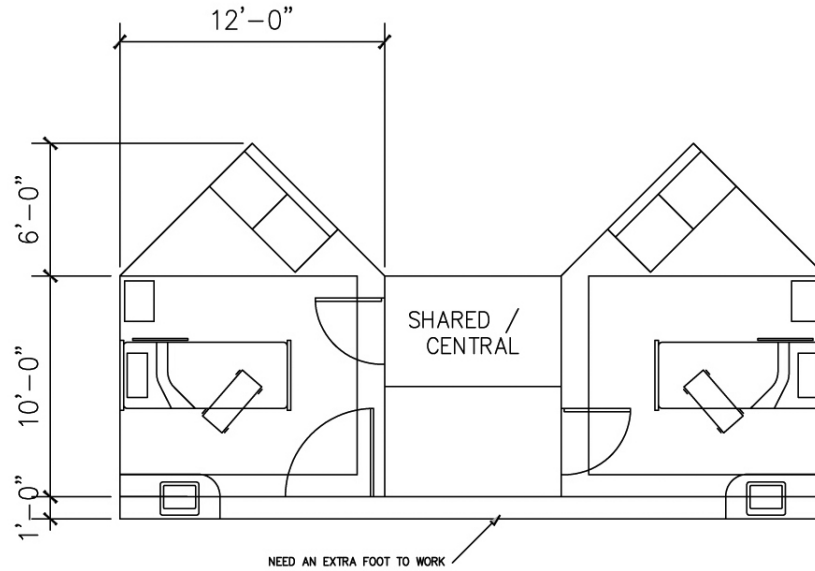


ZGF Hospital Daylight Testing - Test 25

rank = 21

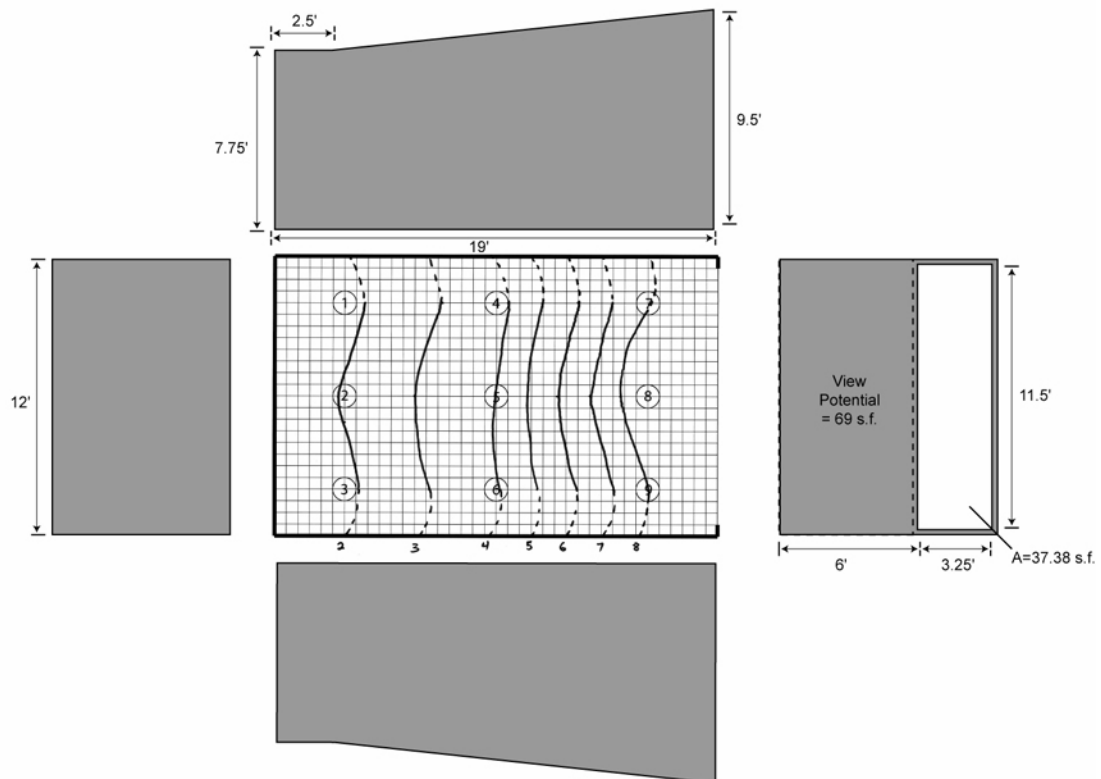


- **Model 25** - This configuration was a modified version of Model 13 with a 12' width and a 16' depth. The daylight window had a glazing area of 48 s.f. and a view opportunity of 97.75 s.f. The glare constant from the daylight window was 162.

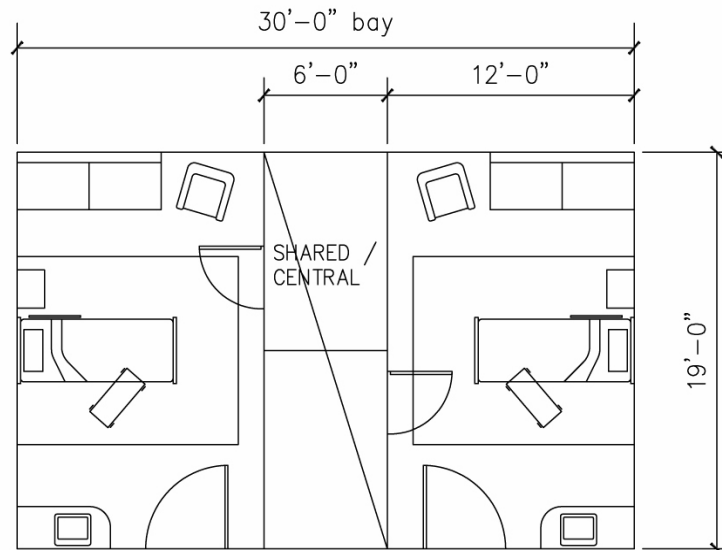


ZGF Hospital Daylight Testing - Test 26

rank = 11

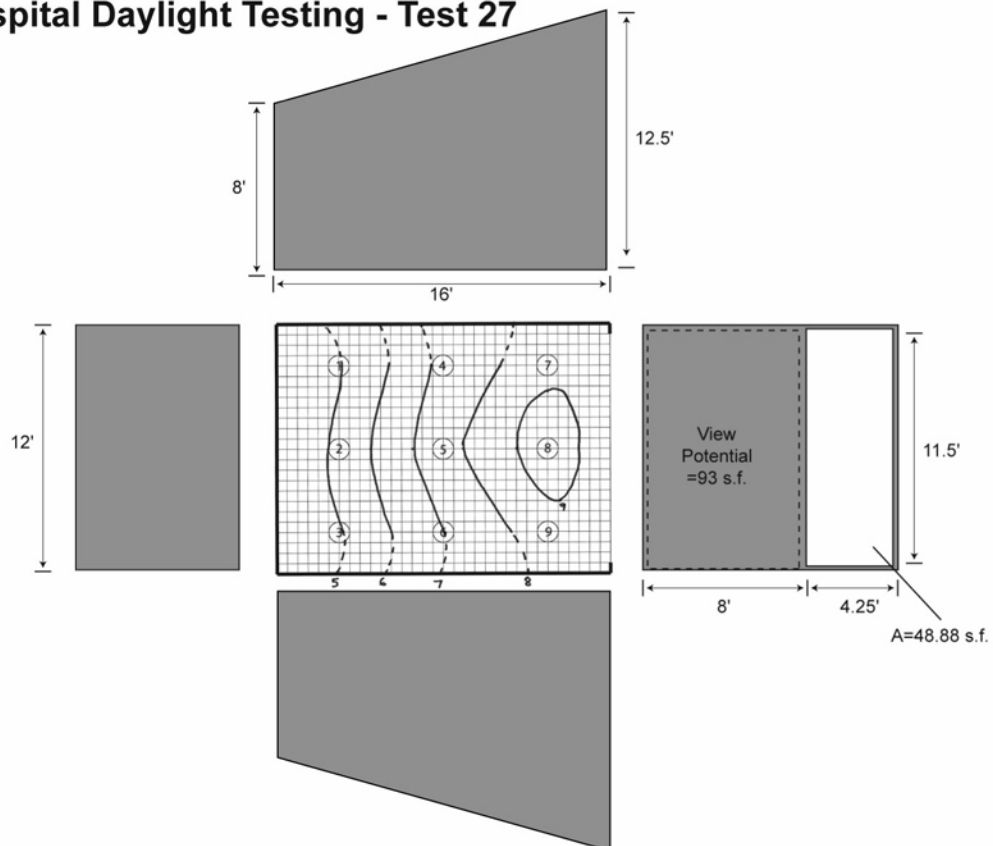


- Model 26** - This configuration was a modified version of Model 14 with a 12' width. The daylight window had a glazing area of 37.38 s.f. and a view opportunity of 69 s.f. The glare constant from the daylight window was 134.

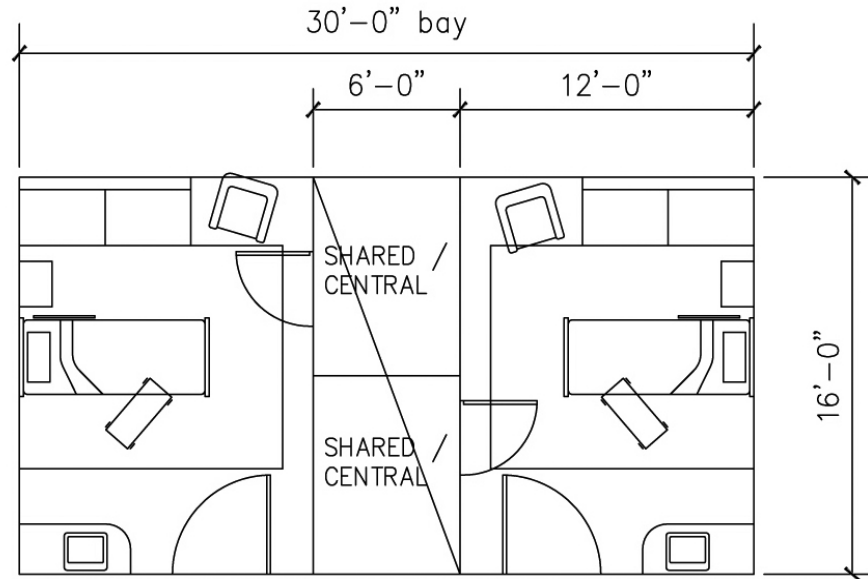


ZGF Hospital Daylight Testing - Test 27

rank = 9

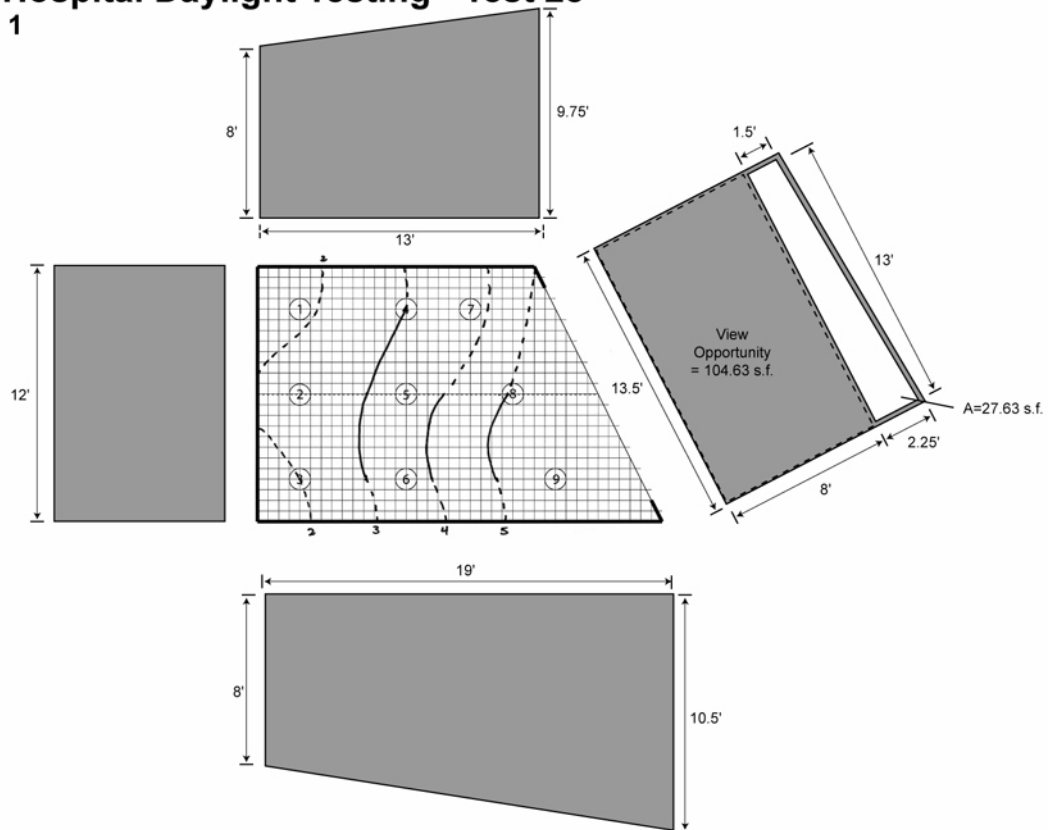


- **Model 27** - This configuration was a modified version of Model 16 with a 12' width. The daylight window had a glazing area of 48.88 s.f. and a view opportunity of 93 s.f. The glare constant from the daylight window was 64.

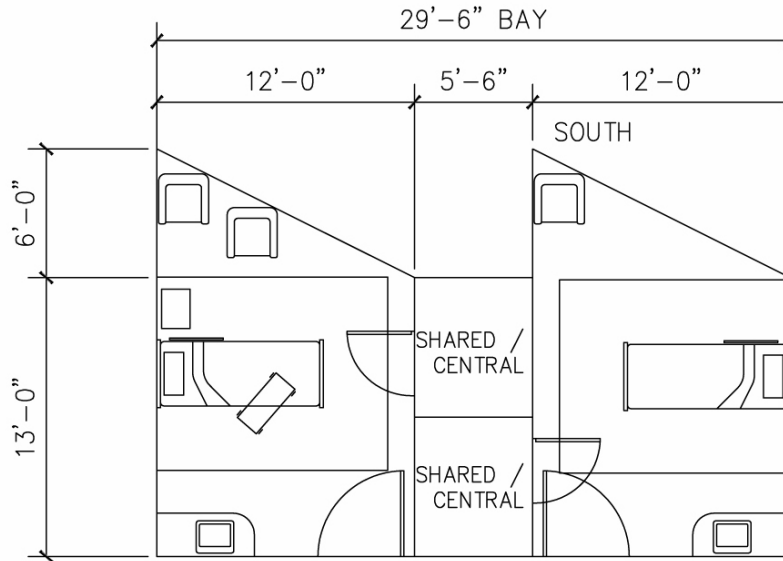


ZGF Hospital Daylight Testing - Test 28

rank = 1

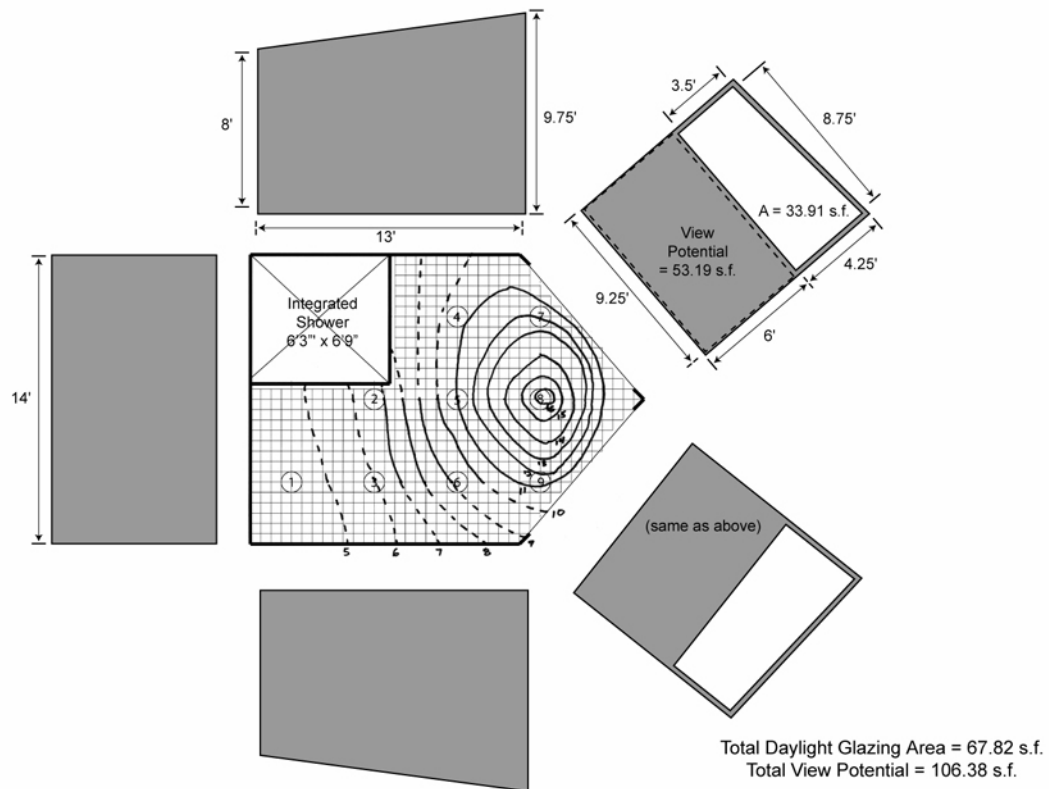


- Model 28** - This configuration was a modified version of Model 21 with a 12' width. The daylight window had a glazing area of 27.63 s.f. and a view opportunity of 104.63 s.f. The glare constant from the daylight window was 74.



ZGF Hospital Daylight Testing - Test 29

rank = 23



- **Model 29** - This configuration was a modified version of Model 19 with an inboard integrated shower toilet room. The glare constant from the daylight windows was 142.

